THE RESOURCES AGENCY OF CALIFORNIA

Department of Water Resources

BULLETIN No. 98

NORTHEASTERN COUNTIES GROUND WATER INVESTIGATION

VOLUME I

TEXT

FEBRUARY 1963

EDMUND G. BROWN
Governor
State of California

WILLIAM E. WARNE
Administrator
The Resources Agency of California
and Director
Department of Water Resources

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DEPARTMENT OF WATER RESOURCES

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November 29, 1962

Honorable Edmund G. Brown, Governor, and
Members of the Legislature of the
State of California

Gentlemen:

I have the honor to transmit herewith Bulletin No. 98, "Northeastern Counties Ground Water Investigation." This bulletin summarizes the investigation approved by the Legislature and for which funds were first appropriated by the Budget Act of 1957 (Item 263.c).

Bulletin No. 98 includes plates showing the most detailed areal geology of the northeastern counties published to date. The bulletin also presents the first published information concerning the subsurface geology of the ground water basins within this area. Based upon geologic and all other data collected during this investigation, preliminary evaluations of the potential for ground water development within these ground water basins of the northeastern counties are presented.

Sincerely yours,

William E. Warne

Director

STATE OF CALIFORNIA
THE RESOURCES AGENCY OF CALIFORNIA
DEPARTMENT OF WATER RESOURCES

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ACKNOWLEDGMENT

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California Division of Forestry
California Division of Highways
California Division of Mines and Geology

Sierra-Pacific Power Company
Western Pacific Railroad

CHAPTER I. INTRODUCTION

Development of the water resources of California requires that investigations be initiated many years prior to the need for water to insure proper economic growth. Recommendations concerning the development of California's water resources should be based upon consideration of all means of supplying foreseeable demands. The utilization of ground water in conjunction with plans to develop surface supplies is one method of providing future supplies when needed.

Previous investigations have determined that the northern part of the State as a whole produces more water than it requires for full development. Unfortunately, this excess water is not equally available to all parts of Northern California. Areas in the northeastern part of the State are so located that economical development of surface supplies cannot satisfy predicted needs for water. Knowledge concerning the ground water resources within these areas has been lacking in the past but is needed so that continued development of this valuable segment of the water supply can be realized.

The primary aim of the Northeastern Counties Ground Water Investigation was to make the studies necessary to establish a factual basis for evaluating the ground water potential of several ground water basins located in Northeastern California. Preliminary evaluations of this potential based upon the data collected are presented and discussed in this bulletin. Additional investigations and considerable study will be required to evaluate fully the potential for ground water development within the areas investigated.

Origin and Authorization for Investigation

The need for a study of the ground water potential of several ground water basins in Northeastern California was shown by past investigations by the Department of Water Resources. A comprehensive survey of the water supplies, water needs, and possible water developments within this area was made as part of the statewide water resources investigation conducted under the direction of the California State Water Resources Board during the period from 1947 to 1957. Encompassing the entire State, the study was conducted and reported upon in three phases.

The first phase consisted of an inventory of the basic water resources of the State. Bulletin No. 1, "Water Resources of California," published in 1951, presented a compilation of data on precipitation, natural stream runoff, flood flows, and water quality.

The second phase involved estimates of present and ultimate water requirements on a statewide basis. Bulletin No. 2, "Water Utilization and Requirements of California," June 1955, includes determinations of present use of water for consumptive purposes and forecasts of ultimate water requirements based upon the capability of the land to support further development.

The concluding phase of the statewide investigation is contained in Bulletin No. 3, "The California Water Plan," dated May 1957. The California Water Plan has been adopted by the Legislature as a comprehensive master plan to guide and coordinate the activities of all agencies for developing California's water resources for all beneficial purposes. In general, it shows that the water supply of the State is sufficient and can be properly developed to meet the forecasted future demands for water. The statewide investigation pointed out many problems and recommended continuing studies for their further analysis.

An area containing many problems associated with its present and potential water development comprises the 15 northeastern counties of Butte, Colusa, Glenn, Lake, Lassen, Modoc, Plumas, Shasta, Sierra, Siskiyou, Sutter, Tehama, Trinity, Yolo, and Yuba. In 1954 the Legislature provided for an investigation and determination of ultimate water needs of these counties, predicated upon the full development of all other natural resources. This study included a much more detailed analysis of both water supply and water requirements than was possible in the statewide study.

The results, published in Bulletin No. 58, "Northeastern Counties Investigation," dated June 1960[1/], showed that ultimate water requirements for some portions of the northeastern counties would exceed the potential surface water supplies that could be developed economically from local sources. The areas with limited water supplies are mainly within the mountain valleys east of the Cascade Range and Sierra Nevada in Modoc, Lassen, Plumas, and Sierra Counties. A reconnaissance study of the geology and ground water conditions within these valleys, made as part of the Northeastern Counties Investigation, showed that more detailed investigation of the potential for ground water development was warranted.

The Department of Water Resources proposed in 1956 that a thorough investigation be made of ten ground water basins in the northeastern counties as part of the California Water Development Program. The valleys proposed to be included were Goose Lake, South Fork of Pit River, Big Valley, and Fall River Valley, all within the Pit River Drainage Area; Surprise Valley, Madeline Plains, Willow Creek Valley, and Honey Lake Valley, all closed basins; and Sierra Valley and Mohawk Valley within the Feather River Drainage Area. Most of these were shown in Bulletin No. 58 to have ultimate water requirements in excess of their available surface water supply.

1/ The preliminary edition was published in December 1957.

The Legislature approved the proposal for the Northeastern Counties Ground Water Investigation, and in the Budget Act of 1957 (Item 263.c) appropriated $75,490 to begin work. During the five fiscal years from 1957-58 through 1961-62, a total of about $560,000 was made available to carry this work to completion.

Objective and Scope of Investigation

The original objective of the Northeastern Counties Ground Water Investigation was to collect all data relevant to the occurrence and movement of ground water in the ten basins, to analyze the hydrology of the ground water basins and to estimate the probable safe yield and potential for development of each basin. The data collection program was initiated to provide information regarding the extent and character of the ground water basins, the number of wells, amounts of water produced by the wells, and other factors to aid in the evaluations. Prior to this investigation there had been no comprehensive studies of ground water in any of these areas. There were no data available on the locations of wells or historical water levels. Existing geological information was generalized for broad areas or developed in detail for limited areas for such purposes as mining or damsite studies.

Field investigations for this investigation disclosed that the limited development of the ground water in some basins would not provide sufficient data to determine items such as specific yield, storage capacity, and changes in the volume of ground water storage, needed for quantitative evaluation of the potential for ground water development. As a result, studies of water supply and water use to estimate safe ground water yield could not be completed. Quantitative estimates of the missing items needed for the hydrologic analysis of several ground water basins were made, but the results were inconclusive.

Therefore, much of the emphasis of this investigation was placed on the collection of data regarding wells and water levels and on detailed study of the geology of the ground water basins. The investigation of geologic conditions was intensely pursued as the foundation to understanding the characteristics of the ground water basins.

The information collected was extremely useful, and from it preliminary general evaluations have been made of the potential for ground water development. Considerable emphasis was placed upon correlation and analysis of data pertaining to the occurrence and movement of ground water. Such data were obtained by conducting geologic studies to ascertain the characteristics of the water-bearing formations, by collecting information relating to the yield of wells, by measuring water levels in wells, and by taking water samples so the quality of water could be analyzed. Many precipitation stations were established by the department and maintained by residents of the area to provide rainfall measurements in areas for which no data previously existed. Details of the geologic investigations and water quality studies are contained in unpublished office reports prepared during the investigation. Basic data obtained by the continuing data collection activities of the department will appear in future publications. The evaluations of the ground water potential in each basin are shown on plates which will be presented and discussed in this bulletin.

The investigation showed that ground water may provide an economical source of water supply in conjunction with surface supplies. The data collected and compiled during this investigation should also provide the basis for future comprehensive quantitative evaluations of the potential for ground water development.

Geologic Data

A geologic mapping program was initiated for each ground water basin investigated. The area mapped for each basin was scheduled to include as much of the probable recharge areas as possible. Because of the close proximity of adjoining recharge areas, the mapping program when completed provided full coverage of the entire region of Northeastern California in which the several basins are located. The geologic mapping program began with compilation of all available published and unpublished geologic maps and reports of the region. Original geologic mapping was then carried out as needed for this investigation, particularly in the main valley areas.

Subsurface geologic conditions were evaluated initially from data obtained from logs of water wells. Additional subsurface data were collected from test holes drilled during the investigation. Seven test holes were drilled in Surprise Valley, and samples of water-bearing and nonwater-bearing materials were studied. These test holes ranged in depth from 13 to 301 feet. Twenty-two test holes were drilled in Big Valley. Of these latter holes, 20 were auger holes ranging in depth from 20 to 24 feet. The other two were deep test holes and were drilled to depths of 1,231 feet and 1,843 feet, respectively. Samples were obtained from both deep test holes, and an electric log and a micro-log were made of the deeper hole.

Additional subsurface data were collected from gravimetric studies made in Big Valley, Sierra Valley, Surprise Valley, and Honey Lake Valley. Through evaluation of data collected in these surveys, the probable depth to bedrock beneath the floor of the valley was determined. In addition, the locations of many of the faults which pass beneath the valley floor were ascertained. A seismic survey was made for a portion of Sierra Valley in cooperation with the United States Geological Survey. The seismic survey

provided information to evaluate the depth to bedrock and the probable location and extent of several buried lava flows.

Well Data

In each valley as many wells as possible were located and examined. Information was sought from owners and well drillers regarding the subsurface formations into which the wells were drilled, the elevations of water in the wells, and the amount of water produced by the wells. Elevation of each of the wells was determined by field surveys. Use was also made of vertical control surveys conducted by other agencies.

A program to make periodic measurements of depth to ground water was established for selected wells throughout the valleys. As a result of the Northeastern Counties Ground Water Investigation, well measurements will continue to be made monthly for a few wells within the valleys as part of the department's ground water measurement program. In addition, over 500 wells will be measured once every five years and used to prepare maps showing lines of equal elevation of water in wells.

Table 1 lists well data available for the ground water basins investigated and indicates the relative degree of development in the several basins. Most of the wells have been developed for domestic or stock purposes, and comparatively few are used for irrigation, industrial, or municipal purposes. Table 1, in addition to listing the present use of wells, also indicates the availability of additional information concerning these wells. In the course of the current investigation, 488 well logs were obtained from various sources. The information contained therein was useful in evaluating the geology of the area.

In interviews with owners and well drillers, information obtained concerning the yield of wells gave some indication as to the quantity of

TABLE 1

WELL DATA AVAILABLE FOR GROUND WATER BASINS INVESTIGATED

Ground water basin	Number of wells and their primary present use								Number of wells for which data are available		
	Domestic	Irrigation	Industrial	Municipal	Stock	Test	Not in use	Total	Well logs	Yield[a]	Water levels[b]
Central Valley Drainage Basin											
Goose Lake Valley[c]	61	9	5	1	13	---	30	119	6	12	66
Alturas	177	14	5	5	32	---	53	286	9	24	101
Big Valley and Round Valley	259	16	4	3	71	2	90	445	39	24	245
Fall River Valley	153	45	2	2	33	---	15	250	114	42	132
Sierra, Mohawk, and Humbug Valleys[d]	122	13	6	3	187	---	80	411	58	178	226
Lahontan Drainage Basin											
Surprise Valley[c]	150	58	3	1	229	16	65	522	42	233	217
Madeline Plains	34	6	1	---	50	---	66	157	20	9	89
Willow Creek and Secret Valleys[e]	4	3	---	---	6	---	3	16	4	1	9
Honey Lake Valley[c]	401	97	19	5	65	4	192	783	196	119	450
Totals	1,361	261	45	20	686	22	594	2,989	488	842	1,535

a/ Data as to yield in a few instances from tests, but in general from statements of user or developer of well.
b/ Measurements of water levels started in summer or fall of 1957, and semi-annual measurements were made until the end of 1960 with only a few measurements made in 1961.
c/ California portion only.
d/ No water elevation or quality data available for wells in Humbug Valley.
e/ No data available for wells in Secret Valley.

water that could be developed from certain geologic formations. The data collected concerning the elevation of water levels in wells were utilized to prepare maps showing lines of equal elevation of water in wells. All of the information collected pertaining to wells is contained in the files of the Department of Water Resources.

Water Quality Data

To determine the suitability of the ground waters for irrigation and domestic uses, a water quality investigation was undertaken. Following a review of available well data, a group of representative water samples were subjected to a complete mineral analysis. Sanitary analyses were not made because conditions of bacterial contamination, if they existed, would be controlled by Public Health Agencies. Table 2 lists the number of surface and ground water samples analyzed during this investigation for each of the ground water basins studied. All of the water quality information collected during this investigation concerning ground water is contained in the files of the Department of Water Resources.

Precipitation Data

With the cooperation of the local residents in the area of investigation, more than a hundred precipitation stations were established. The precipitation data collected during the investigation were correlated with records from precipitation stations which had long periods of record. All available precipitation data were then utilized to prepare a map of the area showing lines of equal mean seasonal precipitation.

Geography and Economy of the Area of Investigation

The ground water basins included in this investigation are located principally in the four northeastern counties of California, adjacent

TABLE 2

WATER QUALITY ANALYSES

Ground water basins	Number of water quality analyses: Surface water	Ground water
Central Valley Drainage Basin		
Goose Lake Valley[a]	13	38
Alturas	21	74
Big Valley and Round Valley	10	70
Fall River Valley	5	81
Sierra, Mohawk, and Humbug Valleys	16	66
Lahontan Drainage Basin		
Surprise Valley[a]	37	83
Madeline Plains	21	36
Willow Creek Valley and Secret Valley	12[b]	7[b]
Honey Lake Valley[a]	15	155
Total	150	610

(a) California portion only.
(b) All samples indicated were taken in Willow Creek Valley.

to the State of Nevada. These counties, from north to south, are Modoc, which lies adjacent to the State of Oregon, Lassen, Plumas, and Sierra. One ground water basin investigated and its drainage area extends into Siskiyou and Shasta Counties, which are located to the west of Modoc and Lassen Counties. Plate 1, Area of Investigation, shows the valley floor area and the tributary drainage area for each of the ground water basins investigated.1/

Population

The Counties of Modoc, Lassen, Plumas, and Sierra showed decreases in population from 1950 to 1960. Population losses ranged from a 6.8 percent reduction in Sierra County to a 26.4 percent reduction in Lassen County. Mariposa with a 1.6 percent decrease and San Francisco with a 4.5 percent decrease were the only other counties in California to show a population loss in the last decade.

In Figure 1, the census county divisions of each of the counties involved in this investigation are shown. The total population in each census county division is shown in bold print on the figure. Population of the communities located within a census county division is indicated in parentheses and is included in the total shown for each census county division. Population data shown in Figure 1 were obtained from "United States Census of Population, 1960, California, Number of Inhabitants, U. S. Department of Commerce, Bureau of the Census, PC(1), 6A, California."

Alturas, with a 1960 population of 2,819, is the only city reported upon in Modoc County. Of the communities for which population figures are given in Lassen County, only the City of Susanville, with a population of 5,597, is included within the area of investigation. In

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1/ Plates are under separate cover.

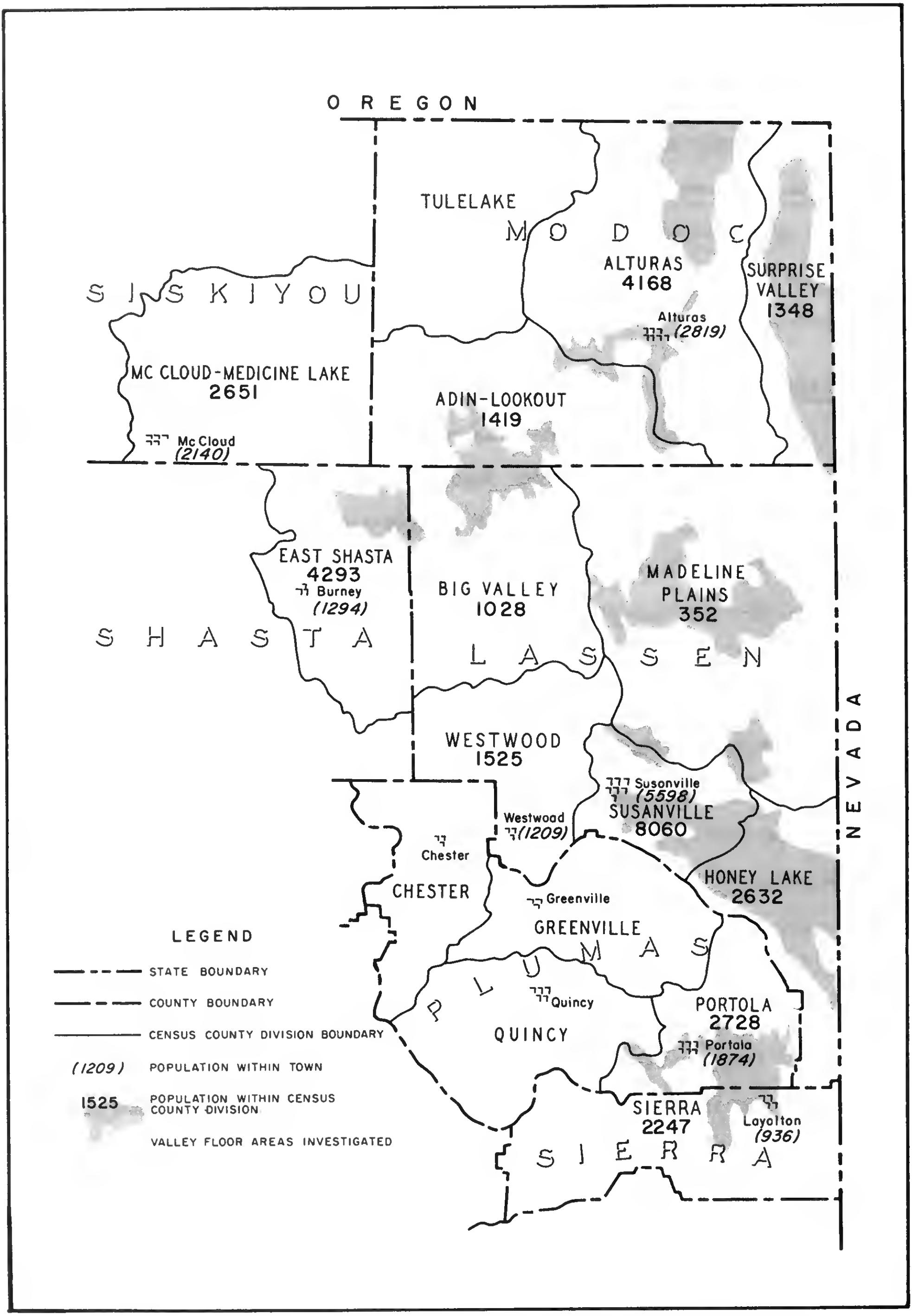


Figure 1. POPULATION WITHIN CENSUS COUNTY DIVISIONS, 1960

Plumas County, four communities are shown but only the City of Portola, with a population of 1,874, is within the study area. Loyalton, with a population of 936, is the only city in Sierra County that is within the study area. A few additional towns and villages with smaller populations are included within the rural population of the area of investigation.

Plumas County has a population density of 4.5 persons per square mile; Lassen, 3.0; Sierra, 2.3; and Modoc, 2.0. Only three other counties in California have population densities lower than Modoc County. They are Alpine with 0.5, Mono with 0.7, and Inyo with 1.2 persons per square mile. The land area and population for 1950 and 1960 for the counties of Modoc, Lassen, Plumas, and Sierra are presented in Table 3.

Present Economy and Development

The present economy of the four counties is based upon the development and use of their existing natural resources. Mining for gold was probably the first important development within the area, but this resource is only of importance in quite limited areas today. Timber was initially used in connection with mining and later became a major segment of the economy. The early settlers found good cattle feed available on the meadow and pasture lands that are in the areas. Agricultural pursuits were first centered upon providing food for those engaged in mining and related activities. Recreation has assumed a more important aspect of the area's economy, as population pressures in the remainder of the State have created demands for additional recreational areas.

Mining. Mining activity within this area today is more concerned with the production of non-metallic minerals than the metals, although some gold continues to be mined in Sierra County. Some prospecting for uranium has been done, but no production has as yet resulted. Commercial

TABLE 3

AREA AND POPULATION OF
NORTHEASTERN COUNTIES: 1950 AND 1960

County	Land area in square miles	Population 1950	Population 1960	Percent decrease
Lassen	4,547	18,474	13,597	26.4
Modoc	4,092	9,678	8,308	14.2
Plumas	2,570	13,519	11,620	14.0
Sierra	958	2,410	2,247	6.8

production of silver, copper, mercury, or other metals has not been too successful.

Sand, gravel, and crushed rock make up a substantial portion of the total production of minerals within the entire area. Throughout portions of the Northeastern Counties, various rocks and minerals are found which are of interest to rock collectors and lapidaries, but they have little commercial value. A type of variegated obsidian found in Modoc County is of particular interest to such collectors.

Timber. There are extensive areas of publicly owned and privately owned forest lands. Quite recently timber production has been significantly cut back from the relatively high rates of production during World War II and post-war years. Much of the population loss is attributable to this cut back. Timber is the most important non-agricultural industry and many mills are found in all of the counties. It is predicted that the future timber harvest will be considerably reduced from the peaks of World War II levels but will continue at a long-term sustained yield basis.

Agriculture. From the beginning of the settlement of this area, the beef industry has been an important segment of the economy because relatively large tracts of land have been available for the grazing of livestock. Natural pastures and range lands are used for cattle grazing. Timbered areas also are grazed to the extent feasible.

Much of the irrigated agriculture within the valley areas is devoted to crops which support livestock. Irrigated pasture, hay, and alfalfa are the principal crops. Only a very small percentage of the irrigated area is used for truck or specialty crops.

Recreation. Tourists, campers, hunters, and fisherman find that the arid deserts, rugged mountains and forest lands of the northeastern

counties contain some of the last remaining primitive areas in California. Big game hunting is an important sport. Rocky Mountain and California mule deer thrive on the seemingly barren lava plateaus; they browse the brush lands, and range over the mountain slopes until advancing winter snows slowly herd them back to lower altitudes. Modoc County is one of the few remaining areas in which antelope hunting is legal. Concentrated hunting of waterfowl occurs in the Goose Lake area, although hunters find waterfowl in other valleys throughout the region. A few pheasants and quail also are found. Good fishing is found in many areas, but lack of access prevents extensive fishing in some of the better trout streams in the region. Of the several lakes within the area, Eagle Lake probably possesses the greatest recreational potential and currently is being developed for more intensive use. Camp and picnic areas have been developed throughout the region. Undoubtedly, recreational activities will become a larger part of the general economy.

Access. Most of the towns and communities in the northeastern counties are accessible by adequate all-weather federal or state highways. U. S. Highways 40 Alternate, 299 and 395 and State Sign Routes 36, 49, 89 and 139 serve the area. Susanville, Alturas, and Portola, the three largest communities in the region, are served by the Southern Pacific Company or the Western Pacific Railroad. Big Valley is also served by the Great Northern Railway, and the Western Pacific Railroad. Most of the population centers have airports, or at least landing strips, nearby.

Soils

High volcanic plateaus and rugged terrain are found in portions of the area, while Madeline Plains and other valley areas are relatively flat. In general, the soils found within the area investigated may be

divided into two broad groups; residual soils, which have developed in place, and transported soils.

Residual soils occur mainly on hilly and mountainous lands. Soil differences largely are dependent upon variation of parent material and climatic factors. Soil depth varies from very shallow on scab lands or lands having considerable rock present on the surface and throughout the soil profile, to good depth on lands having little or no rock present. Drainage is usually good. Suitability of much of these soils for irrigation development is limited because of the complex topographic conditions; however, certain of these soils are suited for many climatically adapted crops.

Transported soils vary in their physical and chemical characteristics according to the nature of the deposition, parent material, and the degree of development that has taken place since their deposition. This group of soils can be broadly classified as old valley fillings, basin and lacustrine soils, and Recent alluvium.

Soils derived from old valley fillings and remnants of former alluvial fans are extensive in many mountain valleys throughout the northeastern counties. These soils have undergone marked changes in profile characteristics since their deposition. Leaching and other soil forming processes have brought about soils varying from those underlain with dense claypans or cemented hardpans to those with moderately compact subsoils. Agriculturally, these soils are generally suitable only for crops with fairly shallow roots.

Basin and lacustrine soils have developed from fine sediments deposited in overflow basins or in fresh water lakes. These soils are normally fine-textured and, due to limited or restricted drainage, an accumulation of salts is often present. Much of the saline soil could

be reclaimed by improvement of local drainage. Certain of the alkali lacustrine soils, because of the greater difficulty in reclamation, were not considered as potentially irrigable, particularly in Surprise Valley and Honey Lake Valley. Otherwise, the basin and lacustrine soils are suitable for many climatically adapted medium and shallow rooted crops.

Recent alluvial soils occupy flood plains adjacent to stream channels. In general, these soils are moderately deep, friable, and medium-textured and have undergone little or no change in their profile characteristics since deposition. These soils are only found to a limited extent in the ground water basin areas of the northeastern counties.

Climate

In the area under investigation, the climatic conditions are influenced to a great extent by the landward movement of water-bearing air masses that originate in the central and northern Pacific Ocean. Abrupt changes in topography, however, cause wide variations in the climate. This is evidenced by the variation of the mean seasonal precipitation from more than 70 inches in a portion of Sierra County to less than 10 inches in eastern Modoc and Lassen Counties. Plate 2, Geographical Distribution of Precipitation in Northeastern California, indicates the variation in mean seasonal precipitation over the area of investigation. Much of the precipitation falls in the form of snow on the higher mountain ranges, although rain above 8,000 feet sometimes occurs. Heavy snowfall is the usual winter feature of the Sierra Nevada at elevations above 5,000 feet. Snow falls in moderate amounts on the mountains and the plateaus in Lassen and Modoc Counties. The northerly and westward movement of the prevailing Pacific high-pressure ridge during the summer results in a practically rainless period during these months, except for local showers and thunderstorms which occur in the mountainous areas.

Temperature, wind movement, and humidity are similarly influenced by the movement of the Pacific Coast air masses and the topography of Northern California. Warm, dry summers characterize the northeastern counties. Maximum daily summer temperatures in the northern plateaus often exceed 100 degrees. In the winter, temperatures are low in the mountains and plateaus, reaching at times -30°F. The mountain valley and plateau areas are usually frost-free from June until the latter part of September, but in many locations frosts may occur in any month of the year.

Drainage Basins and Ground Water Basins

The valley floor areas in which ground water was investigated are located either within the Central Valley or Lahontan Drainage Basins, and are shown as shaded areas on Figure 2. The Central Valley and the Lahontan Drainage Basins are two of the nine major hydrographic divisions of the State of California. The surface drainage areas tributary to each ground water basin were determined primarily from the topographic maps available for the areas. The valley floor area usually cannot be as precisely determined as the surface drainage areas which extend to the crests of the surrounding terrain. The limits of ground water basins are determinable by careful consideration of the geologic and topographic conditions of each ground water basin and occurrence of ground water within the various formations as defined on page 34. The boundaries of the ground water basins were determined for each basin to the extent that data were available and will be presented and discussed in Chapter IV, Ground Water. Table 4 shows the acreage of the drainage and valley floor areas for each basin.

Central Valley Drainage Basin. The areas of investigation within the Central Valley Drainage Basin are located within the Pit River and the Upper Feather River watersheds. The Pit River originates in Modoc County

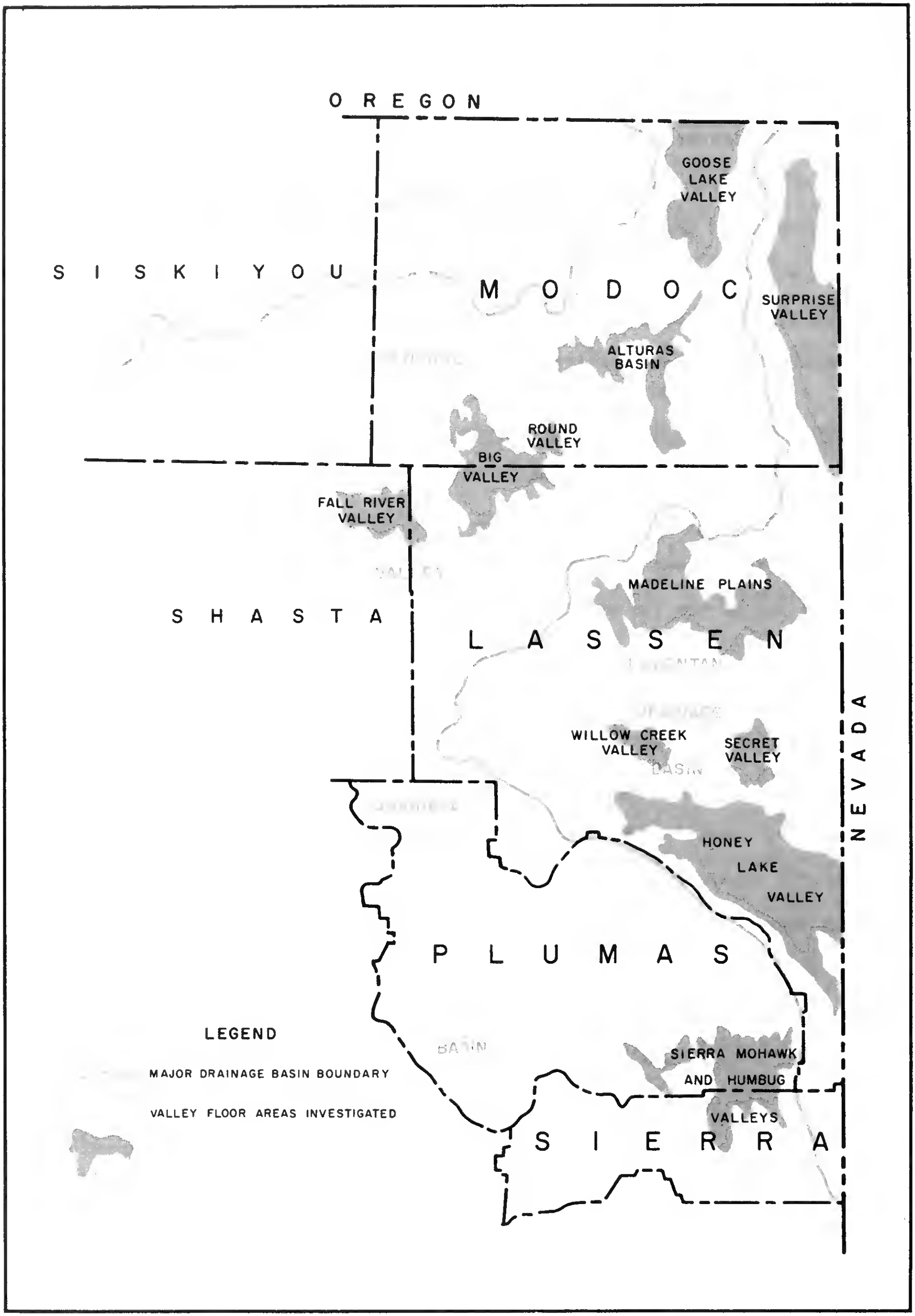


Figure 2. VALLEY FLOOR AREAS INVESTIGATED

TABLE 4

SURFACE DRAINAGE AND VALLEY FLOOR AREAS

(In acres)

Ground water basin	Drainage area (a)		Valley floor area
Central Valley Drainage Basin		mi²	
Goose Lake Valley (b)	260,000	406	121,300
Alturas	835,000	1305	76,500
Big Valley and Round Valley	588,000	919	101,800
Fall River Valley	716,000	1119	53,300
Sierra, Mohawk and Humbug Valleys	467,000	730	151,200
Lahontan Drainage Basin			
Surprise Valley (b)	433,000	677	223,000
Madeline Plains	541,000	845	180,000
Willow Creek Valley	57,000	89	12,500
Secret Valley	219,000	342	31,500
Honey Lake Valley (b)	794,000	1241	310,400

(a) Total tributary drainage area including valley floor area.
(b) California portion only.

and occasionally in the past has carried flows which overflowed from Goose Lake. The Upper Feather River system, more particularly the Middle Fork and its upper tributaries, originates in Plumas and Sierra Counties. Goose Lake Valley, Alturas Basin, Big Valley, Round Valley, and Fall River Valley are the ground water basins investigated within the Pit River tributary drainage area. Sierra, Mohawk, and Humbug Valleys ground water basins were the only ones considered within the Upper Feather River System.

Lahontan Drainage Basin. Within the Lahontan Drainage Basin, Surprise Valley is the most northerly of the ground water basins investigated. About 25 miles to the south is Madeline Plains ground water basin, and about 15 miles further south are the ground water basins of Willow Creek Valley and Secret Valley. Honey Lake Valley ground water basin extends from a point northwest of Honey Lake to a point southeast of the lake and northeasterly of Sierra Valley.

Water Supply and Demands

Evaluation of the available supply and water requirements for the several areas investigated was reported upon in some detail in Department of Water Resources' Bulletin No. 58, "Northeastern Counties Investigation," June 1960. The data contained therein led to the conclusion that surface water supplies would be inadequate to meet ultimate demands in several areas, and that ground water possibly could be utilized to aid in meeting requirements for water. Figure 3 shows the hydrographic units and the numbers assigned to each unit as they appear in Bulletin No. 58.

Water Supply. Data concerning the natural runoff originating in each hydrographic unit within the Central Valley and Lahontan drainage basins within the area of the present investigation have been abstracted from Table 24 of Bulletin No. 58 and appear in Table 5. The estimates of natural

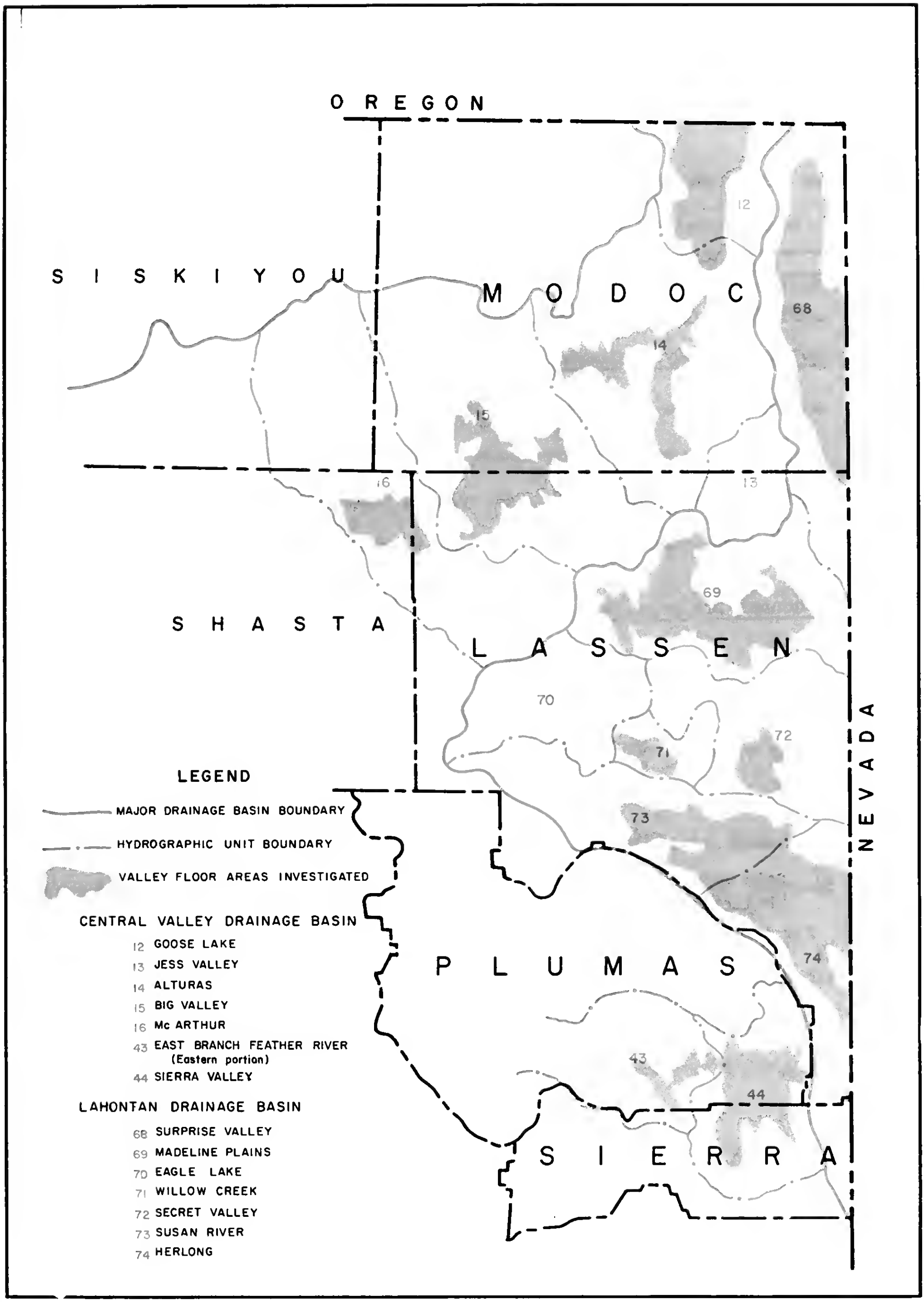


Figure 3. HYDROGRAPHIC UNIT DESIGNATIONS APPEARING IN BULLETIN NO. 58, NORTHEASTERN COUNTIES INVESTIGATION

TABLE 5

ESTIMATED AVERAGE SEASONAL NATURAL RUNOFF[a/]
FROM EACH HYDROGRAPHIC UNIT WITHIN
THE AREA OF INVESTIGATION

(for 34-year period, 1920-21 through 1953-54)

Hydrographic unit: Reference number	Hydrographic unit: Name	Area, in square miles	Runoff, in acre-feet
Central Valley Drainage Basin			
12	Goose Lake	367	50,000[b/]
13	Jess Valley	250	50,000
14	Alturas	1,177	190,000
15	Big Valley	1,243	180,000
16	McArthur	1,218	910,000
44	Sierra Valley	526	130,000
Lahontan Drainage Basin			
68	Surprise Valley	776	180,000
69	Madeline Plains	802	60,000
70	Eagle Lake	435	40,000
71	Willow Creek	145	20,000
72	Secret Valley	651	40,000
73	Susan River	580	100,000
74	Herlong	567	30,000

a/ Data extracted from Table 24, Department of Water Resources "Bulletin No. 58."

b/ That portion of runoff which originates in California only. Waters originating in Oregon are available for some utilization in this area.

runoff contained in Table 5 represent the runoff which would occur within each specific area, shown on Figure 3, under natural conditions and do not include runoff from upstream tributary drainage areas.

Demands. Future demands for water within each hydrographic unit also were evaluated from Bulletin No. 58, and pertinent abstracts from Table 53 and Table 55 are shown in Table 6. Under the column headed "Probable Ultimate" are listed the quantities of water needed to satisfy projected ultimate demands within each of the hydrographic units. Bulletin No. 58 concluded that ultimate water requirements in some areas would be limited because of the lack of available water supply. Under the column headed "Limited Probable Ultimate" appear the quantities that could probably be developed and utilized. The development of a water supply to meet limited probable ultimate demands requires increased use of the ground water potential for such an area.

Organization of Report

Chapter II, Geology and Hydrology, presents the elements of geology and hydrology that form the basis for ground water evaluations. Chapter III, Geologic History and Formations, briefly outlines the geologic history of Northeastern California. A discussion of the geologic and water-bearing characteristics of each of the formations found in the area is also set forth. Chapter IV, Ground Water, summarizes for each basin the preliminary evaluations of ground water based upon the available data for each basin. Chapter V, Concluding Remarks, outlines the accomplishments of this investigation and presents conclusions and recommendations.

An annotated bibliography of reference material used in the course of the investigation immediately follows the test. Plates, because of their size, are included under a separate cover. Photographs, figures, and tables are found throughout the text.

TABLE 6

ESTIMATED ULTIMATE AND LIMITED ULTIMATE MEAN[a/]
SEASONAL WATER REQUIREMENTS IN EACH HYDROGRAPHIC
UNIT WITHIN THE AREA OF INVESTIGATION

(in acre-feet)

Hydrographic unit		Water requirements	
Reference number	Name	Probable ultimate	Limited probable ultimate
Central Valley Drainage Basin			
12	Goose Lake	120,300	120,300
13	Jess Valley	26,000	26,000
14	*Alturas	304,900	211,400
15	*Big Valley	219,800	179,600
16	McArthur	157,000	157,000
44	*Sierra Valley	219,800	138,100
Lahontan Drainage Basin			
68	*Surprise Valley	277,900	119,300
69	*Madeline Plains	466,800	36,000
70	*Eagle Lake	46,600	40,100
71	*Willow Creek	41,900	20,500[b/]
72	*Secret Valley	57,500	41,000
73	*Susan River	215,200	118,900
74	*Herlong	244,000	27,200

* Hydrographic units in which probable ultimate water requirement would be limited by available water supply.

a/ Data extracted from Tables 53 and 55, Department of Water Resources "Bulletin No. 58."

b/ Limited probable ultimate water requirement for Willow Creek hydrographic unit of 41,900 acre-feet shown in "Bulletin No. 58" was a typographical error. Correct value is 20,500 acre-feet.

CHAPTER II. GEOLOGY AND HYDROLOGY

The geologic aspects of a ground water basin and the hydrology of the area provide the basis upon which evaluations of the ground water conditions of each basin have been made. This chapter discusses the elements involved in description and evaluation of ground water basins. Chapter IV presents the description and evaluation of each ground water basin investigated.

Geology: A Fundamental Part of Ground Water Studies

Ground water exists at many places beneath the surface of the earth. It is usually hidden from view but frequently can be seen flowing from springs and wells or seeping into tunnels. Certain properties of geologic materials control the ability of ground water to enter into, move through, be stored in, or be extracted from the ground. Therefore, an understanding of the geology of the Northeastern Counties is necessary to gain an understanding of the ground water found within the basins investigated. Furthermore, an explanation of geologic concepts and terms used is necessary for complete understanding of much of this report.

Geologic Formations

A geologic formation is a fairly widespread group of rocks related in origin, age, and composition. Only a few formations in Northeastern California have been named due to a lack of previous geologic study of the area, but the remaining materials can be subdivided on the basis of age and composition. The discussion of the geologic formations of Northeastern California beginning on page 50 indicates for each formation its map symbol and describes its general location, extent, physical characteristics, and water-bearing

characteristics. For the purpose of this report, the rocks have been divided into three main groups: basement complex rocks of pre-Tertiary age, volcanic rocks of Tertiary-Quaternary age, and sedimentary deposits of Tertiary-Quaternary age. A discussion of the important water-bearing features of each geologic unit is contained in Chapter IV for each ground water basin studied. Also included in Chapter IV are stratigraphic columns for each basin. The stratigraphic column presents the various geologic units found in the basin and is arranged in chronological order. The column includes a summary of the physical and water-bearing properties of each geologic unit or formation.

Table 7 shows the areal distribution of the various geologic units and their relative water-bearing importance.

Geologic Structure

To the average person, the rocks making up the crust of the earth appear to be solid and nearly unbreakable. However, the crust is actually somewhat plastic. This is demonstrated by the forces which slowly bend and squeeze the bedrock upward into folds called anticlines (⌢) and downward into folds called synclines (⌣). If conditions are such that folding cannot relieve the strain, then rupture and movement accompanied by an earthquake occurs along a plane called a fault. The movement may be in either a horizontal or vertical direction or a combination of both. During movement, the materials along the fault sometimes become ground up into a mass of clay called gouge. If the rock is hard and brittle, no gouge may develop and the fault zone becomes filled with rubble. If vertical movement along a fault creates a cliff, it is called a fault scarp.

TABLE 7

DISTRIBUTION AND WATER-BEARING IMPORTANCE OF GEOLOGIC UNITS IN NORTHEASTERN CALIFORNIA

GEOLOGIC UNIT	SYMBOL	Ground Water Basin								
		ALTURAS	BIG VALLEY and ROUND VALLEY	FALL RIVER VALLEY	GOOSE LAKE VALLEY	HONEY LAKE VALLEY	MADELINE PLAINS	SIERRA, MOHAWK, and HUMBUG VALLEYS	SURPRISE VALLEY	WILLOW CREEK and SECRET VALLEYS
SEDIMENTARY ROCKS										
Sand dunes	(Qsd)				O		O		O	O
Sand and silt deposits	(Qs)					O		O	O	
Recent lake deposits	(Ql)				O	O			S	O
Landslides	(Qls)	O				M				O
Talus	(Qto)	S		S						
Muck and peat deposits	(Qmp)	O								
Basin deposits	(Qb)	S	S	O	S	S		S	S	S
INTERMEDIATE ALLUVIUM	(Qal)	M	M	M	M	M	M	M	M	M
ALLUVIAL FANS	(Qf)	L	M	M	L	L	M	L	L	M
Terraces	(Qt)				M			M		
NEAR-SHORE DEPOSITS	(Qps)	M		M	L	L	M	M	L	
PLEISTOCENE AND LAHONTAN LAKE DEPOSITS	(Qpl)			M		L	S	L		
Glacial outwash	(Qpo)							M		
Moraines	(Qpm)							S	S*	
ALTURAS FORMATION	(TQa)	L			M*					
BIEBER FORMATION	(TQb)		M							
PLIOCENE LAKE DEPOSITS	(Tpl)			M*		M	M*	M*		M
Forty-nine Camp formation	(Tmfc)								M	
Deep Creek conglomerate	(TΦdc)								O	
Auriferous gravels	(Teg)					S*				
Gold Run sandstone	(Tgs)					S				
Fort Sage sandstone	(Tfs)					O				
VOLCANIC ROCKS										
RECENT BASALT	(Qrvb)			L						L
Cinder cones	(✻)	O		S						O
PLEISTOCENE BASALT	(Qpvb)	M	L	L	L	L	L	L		L
Pleistocene pyroclastic rocks	(Qpvp)	O		O		O	O			O
PLIO-PLEISTOCENE BASALT	(TQvb)	M			L	M	L		M	L
Plio-Pleistocene pyroclastic rocks	(TQvp)					O	O			O
Warm Springs tuff	(TQvt)	S								
Pliocene basalt	(Tpvb)	S	M	S			O			M
Pliocene andesite	(Tpva)	O	O	O			O			O
Pliocene pyroclastic rocks	(Tpvp)			O		O	O			O
Rhyolite	(Tvr)	O	O		O		O	O	O	
Miocene volcanic rocks	(Tmv)				O					
Miocene basalt	(Tmvb)	O		S	O		O		M	
Miocene andesite	(Tmva)	O			O				O	
Miocene pyroclastic rocks	(Tmvp)	S					S		O	
Big Valley Mountains volcanic series	(Tvb)		S	S						
Turner Creek formation	(Tmtc)	S	M				S			
Cedarville series	(Tmc)	O			O				O	
Sierran volcanic rocks	(Tsv)					O		O		
Sierran basalt	(Tsvb)					S*		S		
Sierran andesite	(Tsva)					O		O		
Sierran pyroclastic rocks	(Tsvp)					O		O		
BASEMENT COMPLEX										
Granitic rocks	(JKgr)					S		O		O
Metamorphic rocks	(pKm)							O		O

NOTE: Principal water yielding units are indicated by bold face type.

L – May transmit or yield large amounts of ground water.

M – May transmit or yield moderate amounts of ground water.

S – May yield small quantities of ground water, generally sufficient only for domestic or stock uses.

O – Yields little or no ground water.

* – Water bearing importance restricted to areas away from valley floor.

Northeastern California is an intensely faulted area. At least four major faults and numerous lesser ones occur in the area. Some of these faults stretch for many miles and several have up to 7,000 feet of vertical displacement. The faulting has broken the crust of the earth into huge, uplifted mountain ranges flanked by low-lying valleys. The faults characteristically present bold, jagged scarps which can be seen for miles as they bound one side of a mountain or mountain range. The most notable fault block mountains, large masses of rock that have been pushed bodily upward, are the Warner and Diamond Mountains. Surprise Valley and Mohawk Valley are relatively narrow trenches bounded on the two longer sides by nearly parallel faults.

Folding on a regional scale in Northeastern California is of less significance than is regional faulting. There is one series of northwest trending anticlines and synclines in northern Lassen and southern Modoc Counties. Synclines form Big Valley and the Alturas Basin, with anticlines occurring in the intervening areas. Neither the synclines nor the anticlines are simple folds. The large syncline in the Alturas Basin has been faulted and also contains several minor anticlines and synclines. The major anticlinal areas have been further faulted and tilted, so that now the tilted fault block structure is predominant.

The Geologic Map

One of the phases of a study of ground water geology is the compilation of a geologic map showing the surface exposures of the various formations. Through the combined use of the geologic map and the geologic sections, a three dimensional geologic model of an area can be visualized. (See geologic maps and sections listed under Plates.)

The various formations are designated on the map by letter symbols. Each symbol contains letters representing the age and either the rock type or the formational name. For example, Pleistocene basalt is designated by the symbol "Qpvb." The first two letters stand for the age of the material, in this case Quaternary period and Pleistocene epoch, the third for volcanic rocks, and the last for basalt.

The Relationship Between the Geologic Materials and Ground Water

Nearly all of the materials that make up the surface of the earth have open spaces which may contain ground water. The size of these openings ranges from minute pores in clays and small fractures found in many consolidated rocks to large lava tubes found in some basalt flows. The porosity, or percentage of the total volume of a material occupied by voids, is not necessarily indicative of the ease with which ground water can move through the material. If the openings are very small, or are not connected, the material is said to have a low permeability even though its porosity may be high. Thus materials of low permeability and high porosity such as clay and tuff transmit very little water. In contrast, materials of high permeability but somewhat lower porosity can yield large amounts of ground water. Materials of this latter type include fractured basalt and mixtures of coarse gravel and sand.

A geologic formation or part of a formation which readily transmits ground water (i.e., has high permeability) is called an aquifer. In contrast, materials which contain ground water but do not transmit extractable quantities (i.e., have low permeability) are called aquicludes. Certain rocks, such as non-fractured granite, neither absorb nor transmit water as they are practically impermeable; a rock of this type is called an aquifuge. All geologic formations can be classed either as aquifers, aquicludes, or

aquifuges. However, certain formations may act as an aquifer in one area and an aquiclude in another area because of changes in permeability resulting from changes in physical characteristics of the materials.

Underground water is present in two major zones beneath the ground surface. Figure 4 shows the occurrence of ground water within these zones. In the upper zone, or zone of aeration, most of the openings in the geologic materials are filled partly with air and partly with water. An exception is in the subzone of soil water where conditions approaching saturation may exist due to infiltration of rainfall or water used for irrigation. Another exception is in the capillary subzone which extends from the underlying water table up to the limit of capillary rise of water. Wells cannot produce ground water from the zone of aeration. Where perched ground water occurs, it is contained in an isolated saturated zone separated from the main body of ground water by an underlying impermeable stratum. Well "B" on Figure 5 represents a well producing from perched ground water.

In the lower zone, or zone of saturation, all of the interconnected openings in the geologic materials are filled with ground water. Ground water exists in this zone under unconfined or confined conditions, or under a condition intermediate between the two. An unconfined aquifer is not overlain by impervious materials, and contains water in interconnected openings in the zone of saturation. The water table is the upper surface of an unconfined body of ground water or approximately the level to which water will rise in a well tapping unconfined ground water. Well "D" on Figure 5 represents a well located in an unconfined aquifer. Unconfined ground water flows in the direction of the downward slope of the water table.

A confined aquifer contains ground water overlain by material sufficiently impermeable to isolate the aquifer from overlying aquifers

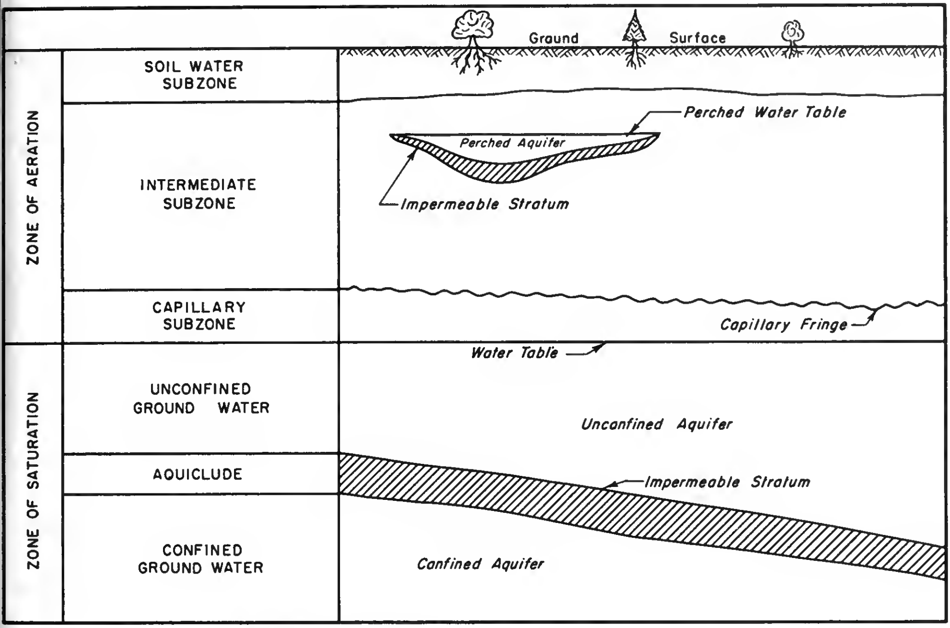


Figure 4 OCCURRENCES OF GROUND WATER

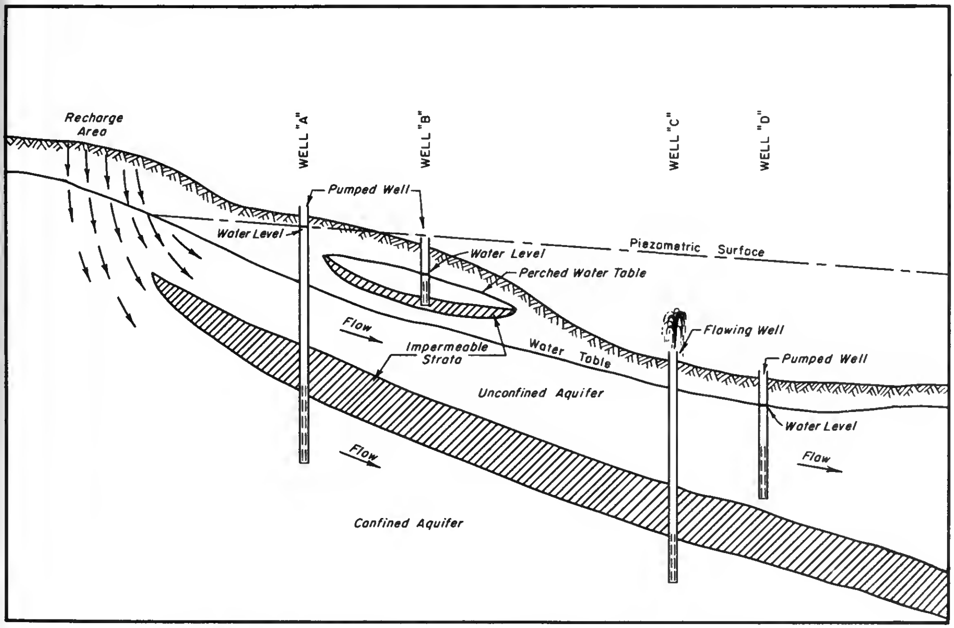


Figure 5 UNCONFINED AND CONFINED GROUND WATER

except in areas of recharge. Confined ground water moves through an aquifer under pressure. The level to which confined ground water will rise in non-pumping wells is the piezometric surface. This surface is a representation of the pressure exerted by the confined ground water on the materials enclosing the confined aquifer. When the piezometric surface is below ground, the water level will rise to some point, as represented by Well "A" on Figure 5. If the piezometric surface is above ground, the well will flow as represented by Well "C".

The stratification of aquifers and aquicludes is the result of deposition under different environments. Coarse-grained deposits, sand and gravel, are laid down principally by streams, and are coarsest at the apex of alluvial fans nearest the mountains. Silts and clays are deposited where streams flood over areas surrounding active channels. Deposition in alluvial basins and in lakes is also principally of fine material, except that near-shore deposits are frequently sandy. As environmental conditions have changed in the geologic past, due to changes in climate, faulting, and folding, the type of deposition has changed and variation in stratification is the result.

The Ground Water Basins

A ground water basin consists of an area underlain by permeable materials which are capable of furnishing a significant water supply; the basin includes both the surface area and the underlying permeable materials. Ground water basins are separated from each other, or may be subdivided into ground water subbasins, by the following features and conditions, listed in approximate order of desirability as boundaries: nonwater-bearing rock, constriction in permeable materials, fault, zone of low

permeability, topographic ridge, shoreline of a lake, or ground water divide. The various ground water basins which are the subject of this investigation are listed in Table 8.

Hydrology: From Precipitation to the Well

The initial source of nearly all ground water is precipitation. Some precipitation immediately infiltrates into the ground, but the remainder becomes runoff and collects in streams and rivers. This surface flow may be used for many purposes or stored for subsequent use. The runoff resulting from precipitation usually has several opportunities to become ground water.

The pattern of movement of a drop of water from the time it enters the ground to the time it emerges either naturally or by pumping from a well is controlled by the subsurface conditions encountered. Upon entering the ground, the water moves downward through the zone of aeration and into the zone of saturation. This happens whenever water from precipitation, streamflow, applied irrigation water and all of the various other sources, moves into the ground through the open spaces in permeable materials. The area over which this is accomplished is called the recharge area. These areas are found on mountains, along foothill slopes, and on valley floors. Important recharge areas often occur in alluvial fan and stream channel deposits below the mouths of canyons. Here the deposits are usually very permeable, allowing for rapid infiltration. In addition, water flows over these recharge areas during all, or at least most, of the year. Areas of younger volcanic rocks such as highly fractured lava flows constitute another important type of recharge area. In this case, the major portion of the precipitation infiltrates and only a minor portion produces streamflow.

TABLE 8

GROUND WATER BASINS

Ground water basins (a) and subbasins: Name	Number (b)	Plate showing areal geology	Plates showing ground water data: Lines of equal elevation	Plates showing ground water data: Potential for development
CENTRAL VALLEY DRAINAGE BASIN				
GOOSE LAKE VALLEY	5-1	3	4 5	6
Willow Ranch	5-1.01			
Davis Creek	5-1.02			
Franklin Creek	5-1.03			
ALTURAS	5-2	7	8	9
South Fork Pit River Valley	5-2.01			
Warm Springs Valley	5-2.02			
BIG VALLEY	5-4	10	11 12	13
ROUND VALLEY	5-36			
FALL RIVER VALLEY	5-5	14	15	16
SIERRA VALLEY	5-12	17	18 19	20
MOHAWK VALLEY	5-11			
HUMBUG VALLEY	5-35			
LAHONTAN DRAINAGE BASIN				
SURPRISE VALLEY	6-1	21	22	23
Upper Alkali Lake	6-1.01			
Middle Alkali Lake	6-1.02			
Lower Alkali Lake	6-1.03			
MADELINE PLAINS	6-2	24	25	26
Madeline	6-2.01			
Ravendale	6-2.02			
Dry Valley	6-2.03			
Grasshopper Valley	6-2.04			
WILLOW CREEK VALLEY	6-3	27	28	29
SECRET VALLEY	6-63			
HONEY LAKE VALLEY	6-4	30	31	32

(a) Capitalized names are basins. Uncapitalized are subbasins. Groupings are arranged in order of discussion in text.

(b) Department of Water Resources numbering system for ground water basins.

Water which passes downward through a permeable material eventually reaches a zone of saturation. This zone contains water under hydrostatic pressure. Under natural conditions, water under hydrostatic pressure moves laterally toward areas of pressure relief, such as springs. In cases where the pressure relief area is a stream channel, springs often form along the channel and help to maintain streamflow during low precipitation periods. If a ground water basin is completely surrounded by impermeable materials and has no surface outflow, ground water movement may terminate in upward seepage to the surface in the lowermost portion of the basin. If a stream flows through and out of the basin, ground water movement may originate or terminate at this stream. Development of wells in a ground water basin diverts some or all of the natural discharge of the ground water to artificial discharge through wells.

The general ground water movement pattern of a valley can be interpreted from maps which show lines of equal elevation of the ground water surface. From such a map, the direction of ground water movement is interpreted as being perpendicular to the contour lines and moving from the higher elevation contour to the lower. The relative spacing between the contour lines indicates the hydraulic gradient of the ground water, which is an index of the resistance encountered as the water moves through the various permeable materials. Other physical barriers which impede the movement of ground water are also indicated by the patterns or spacings of the ground water contours. The effect of faults on the movement of ground water can often be interpreted from the contour maps. Where faults have repositioned a particular water-bearing stratum opposite an impermeable stratum, ground water may rise along the fault zone and appear at the ground surface as springs. If the ground water has percolated deep

enough to become heated and mineralized, it will appear at the surface as a hot spring.

Well Yield: A Function of Geology and Hydrology

The interrelationship of many geologic and hydrologic factors must be known to predict the yield of a well proposed for construction. Some of the more important factors are: the type, depth, and extent of the various subsurface materials; the transmissibility of the various aquifers; the relative locations of the aquifers and the aquicludes; the extent and permeability of the recharge areas; and the availability of water for recharge. When these and other factors are evaluated, an opinion of the ground water development potential of an area can be made.

Proper construction and development methods must be utilized in order to obtain the optimum ground water yield from a well. The two most common methods of drilling an irrigation well are either by using a cable tool rig or a rotary rig. The choice of method is often dependent upon the geologic materials that are expected to be encountered. The cable tool method employs a string of tools suspended from a cable. A bit, alternately raised and dropped, breaks up the material at the bottom of the hole. The broken material is removed from the hole at intervals by a bailer. This method of drilling is frequently used in hard, broken materials such as buried lava flows. The second method is the rotary. This method employs a rotating cutting head. Cuttings are removed by mud-laden drilling fluid which is pumped down through the drill pipe, and then rises to the surface in the space between the drill pipe and the wall of the hole. The rotary method is often used for drilling through bedded sedimentary materials.

After the well has been drilled, steel pipe casing is usually installed. By selectively perforating the well casing, water can be drawn from the desired aquifers and any subsurface strata yielding poor quality water can be sealed off. The well should be properly developed in order to produce the maximum amount of water with a minimum of drawdown. Complete and proper development will also reduce sanding, if it is a problem, and lengthen the economic life of the well. Development usually consists of introducing rapidly moving water into the materials surrounding the well and then reversing the flow. This procedure sorts the geologic materials and results in the removal of fine materials near the casing.

After a well has been developed, a surface seal is usually placed around the casing. This seal prevents any undesirable surface water from flowing into the well. Furthermore, after the pump has been installed, a well intended for domestic use should be adequately chlorinated.

Water Quality

Ground water may be available in abundant quantity but if it is of unsatisfactory quality it may be useless. Water may be unsuitable for beneficial use due to excessive dissolved mineral content. It may have excessive temperature or contain objectionable bacteria and be unfit for use. Bacterial contamination and high temperature are temporary water quality hazards which can usually be corrected readily by treatment or storage. However, problems associated with dissolved minerals usually cannot be easily corrected and therefore mineral criteria have been used in our evaluation of the suitability of water for beneficial use.

Water is an excellent solvent capable of dissolving many minerals and gases. Most of the dissolved substances are in solution as electrically charged particles called ions which can usually be identified and their

concentration measured. When certain of these constituents are present in water in high concentrations they make the water unsuitable for particular beneficial uses. For example excessive sulfate and chloride ion concentrations in irrigation water may prevent plants from obtaining needed moisture and nutrients from the soil. These damaging effects can result in reduced crop yields or complete loss.

Mineral analyses of ground water samples from the Northeastern Counties were made to determine the suitability of the ground water for agricultural and domestic use. These analyses included determinations of four cations, namely, calcium, magnesium, sodium, and potassium; and six anions, namely carbonate, bicarbonate, chloride, sulfate, fluoride and nitrate. The boron and silica content was determined. The pH value and electrical conductivity of each water sample was measured and hardness was also computed.

Measuring the Hazard in Irrigation Water

No rigid criteria for irrigation water quality can be established because there are so many factors which affect the damage that excess of a mineral constituent can cause. Some of the more important of these factors include climate, frequency of irrigation, stage of plant growth, tolerance of the plant, type and texture of the soil, drainage, and use of soil additives.

General criteria, which are quite useful, however, have been developed based upon average climatic conditions, soil properties and normal irrigation practices. A study of the water quality data from Northeastern California as related to these criteria has indicated that only a limited number of the ground water constituents are present in hazardous concentratio

We have evaluated these problem constituents on the basis of the following criteria.

Total Dissolved Solids. The term total dissolved solids refers to the total amount of the various mineral constituents in solution. An excess of total dissolved solids can among other things, limit the availability of moisture to plants and require more frequent irrigation and more intensive soil leaching. The electrical conductivity of water is readily determinable and is a convenient indicator of this salinity hazard. Nearly all irrigation waters which have been used successfully over a long period of time in California possess an electrical conductivity of less than 2,250 micromhos per centimeter and in most cases it is less than 750 micromhos per centimeter. This latter conductivity value is used in this bulletin as the demarcation of salinity hazard.

Sodium. When irrigation waters containing high concentrations of sodium ion are utilized, they can result in the buildup of sodium ion in the soil solution and can modify the soil structure. This will result in poor aeration of the soil, low infiltration rates, and a decrease in the available moisture to plants. In addition, sodium ion may replace calcium ion in the root tissues, resulting in a calcium deficiency which may kill the plant. A numerical value which can be used as an index of sodium or alkali hazard of water is the sodium-adsorption-ratio, referred to as the SAR* value of water. Irrigation waters possessing SAR values of less than 10 and electrical conductivities of less than 750 micromhos per centimeter are considered to be relatively free of sodium hazard. All waters with SAR values greater than 10 are considered to contain some sodium hazard and should be used with care.

$$* \ SAR = \frac{Na^+}{\sqrt{\dfrac{Ca^{++} + Mg^{++}}{2}}}$$

Constituents are expressed in equivalents per million.

Boron. Very low concentrations of boron are essential for plant growth; however, irrigation waters with boron concentrations greater than two parts per million are considered to possess a boron hazard. Excessive boron can cause leaf burn, premature leaf drop, and reduced crop yields. Waters containing concentrations between one-half and two parts per million may be hazardous to specific plants.

Hazards in Domestic Waters

Criteria for domestic waters are generally more stringent than those for irrigation because public health is involved. Both the United States Public Health Service and the State Department of Public Health have established certain standards for drinking water. Some of the mineral constituents of water which are included in these standards have been identified in hazardous concentrations in waters from the northeast counties. They include arsenic, fluoride, iron, and nitrate.

Arsenic. Small amounts of arsenic are found in body tissue but in excess it is considered toxic to man. Concentrations exceeding 0.05 parts per million are considered to be hazardous in drinking water.

Fluoride. Excessive concentrations of fluoride ion may cause mottling of teeth and damage to bone structure. There is increasing evidence that the threshold concentration of fluoride in water for barely detectable mottling of teeth varies with the mean annual air temperature and humidity. The threshold is indicated to be about 0.5 - 0.7 parts per million in warm dry climates while in colder regions the threshold is 1.0 - 1.5 parts per million. Under the prevailing climatic conditions, concentrations over 1.3 parts per million are considered to be excessive within the areas of use in the northeast counties.

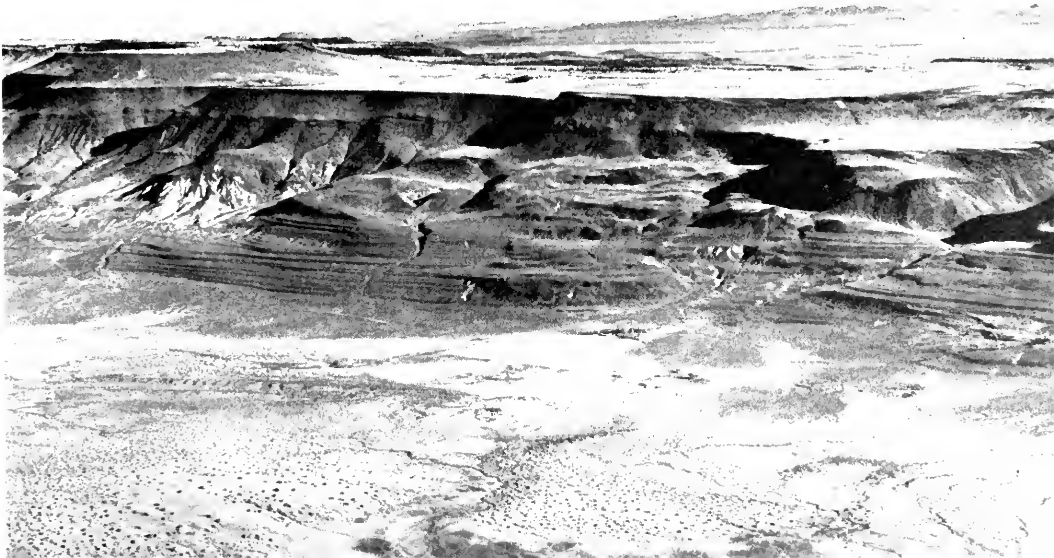
Iron. Trace amounts of iron are essential to nutrition and concentrations found in the ground waters of the Northeastern Counties do not constitute a hazard for physiological reasons. However, waters containing dissolved iron in excess of 0.3 parts per million are considered to be unsuitable for domestic use as they can stain laundry and porcelain fixtures, and may detrimentally affect the taste.

Nitrate. High concentrations of nitrate ion in irrigation waters can be very beneficial to plant life. In domestic waters, however, excessive nitrates are considered as a possible cause of a disease in infants. This disease is characterized by insufficient aeration of the blood. For this reason concentrations of nitrate ions exceeding 45 parts per million in domestic waters are considered to be hazardous.

Warner Mountains, west of Surprise Valley

Water may fall as snow along rugged mountain slopes of the Northeastern Counties or as rain on eroded escarpments of barren plateaus. It may nourish stands of virgin timber or evaporate from the burning surface of alkali flats.

Hays Canyon Range, east of Surprise Valley



Wendel Fan, Honey Lake Valley

Melting snows feed mountain streams which wash silt and stones downslope and spread them in fan-shaped deposits where the canyons widen into broad flat valleys. Much of the water sinks into permeable deposits and percolates into aquifers which extend beneath the valley floor.

Coarse material deposited by Owl Creek, west of Surprise Valley

Goose Lake, Warner Mountains in the background

Some streams drain into broad lakes, shallow and valley bound, from which the waters rarely spill. Others form rivers which meander through farmland and forests, flow quietly past the valley towns, contribute water to the aquifers, and continue to the sea.

Fall River Mills, Fall River in foreground, Pit River above

Road cut west of Fall River Mills

Within upland areas where flowing lavas have cooled and crumbled and faults have fractured the crust of the earth, the water may sink rapidly into the ground.

Devils Garden, southwest of Goose Lake

Cedar Plunge Hot Springs, Surprise Valley

Deep in the earth some of the water contacts superheated rocks containing minerals such as sulphur, boron, and arsenic and later emerges hot, vaporous, and unfit for drinking.

Wendel Hot Springs, Honey Lake Valley

Sprinkler irrigation from ground water, near Pittville

The fields and pastures of the irrigated valley lands are underlain by many aquifers.

Elysian Valley, west of Honey Lake

Artesian stock well, Sierra Valley

Beneath the valleys, impermeable sediments sometimes cap the aquifers and confine ground water under pressure. Drill-
ng through such sediments creates artesian wells from which the waters gush continuously without pumping. Geyser-like, other artesian wells spout thermal waters of poor quality.

Hot spring, east of Cedarville, Surprise Valley

Stock well in Sierra Valley

Powered by winds which sweep the valleys, or by electricity, pumps tap the aquifers to supply water for people, stock, and craps.

Irrigatian well in Honey Lake Valley

CHAPTER III. GEOLOGIC HISTORY AND FORMATIONS

This chapter describes the general geologic history of the northeastern counties of California. Also included in this chapter are descriptions of the physical and water-bearing characteristics of 46 of the different geologic materials particularly pertinent to this investigation.

Geologic History of Northeastern California

Wherever we look today, we see a landscape that is only a brief scene of the ever-changing face of the earth. These changes have been unfolding for hundreds of millions of years. Volcanic eruptions, lands rising and sinking, and oceans coming and going are still in process today just as they have been in the past and will continue to be in the future. The geologic changes that take place during one's lifetime are generally insignificant; for the life of a man is but a fraction of a second in the history of the earth.

Figure 6 presents an overall picture of the geologic time scale back to 600 million years ago. Most of the geologic materials exposed on the surface of the earth were formed during the last three eras, which are the major divisions of geologic time. Of these three eras, the oldest is the Paleozoic, which began about 600 million years ago and lasted some 335 million years. In the northeastern counties area, only a few rocks near Mohawk Valley date from this era. The next era was the Mesozoic, which lasted about 125 million years. Mesozoic rocks occur in many mountain areas south of Honey Lake Valley. Our present era, the Cenozoic, dates back about 60 million years. All of the remaining geologic materials in the northeastern counties of California are of Cenozoic age. Each of the three eras ended with important geologic events, such as changes in climate,

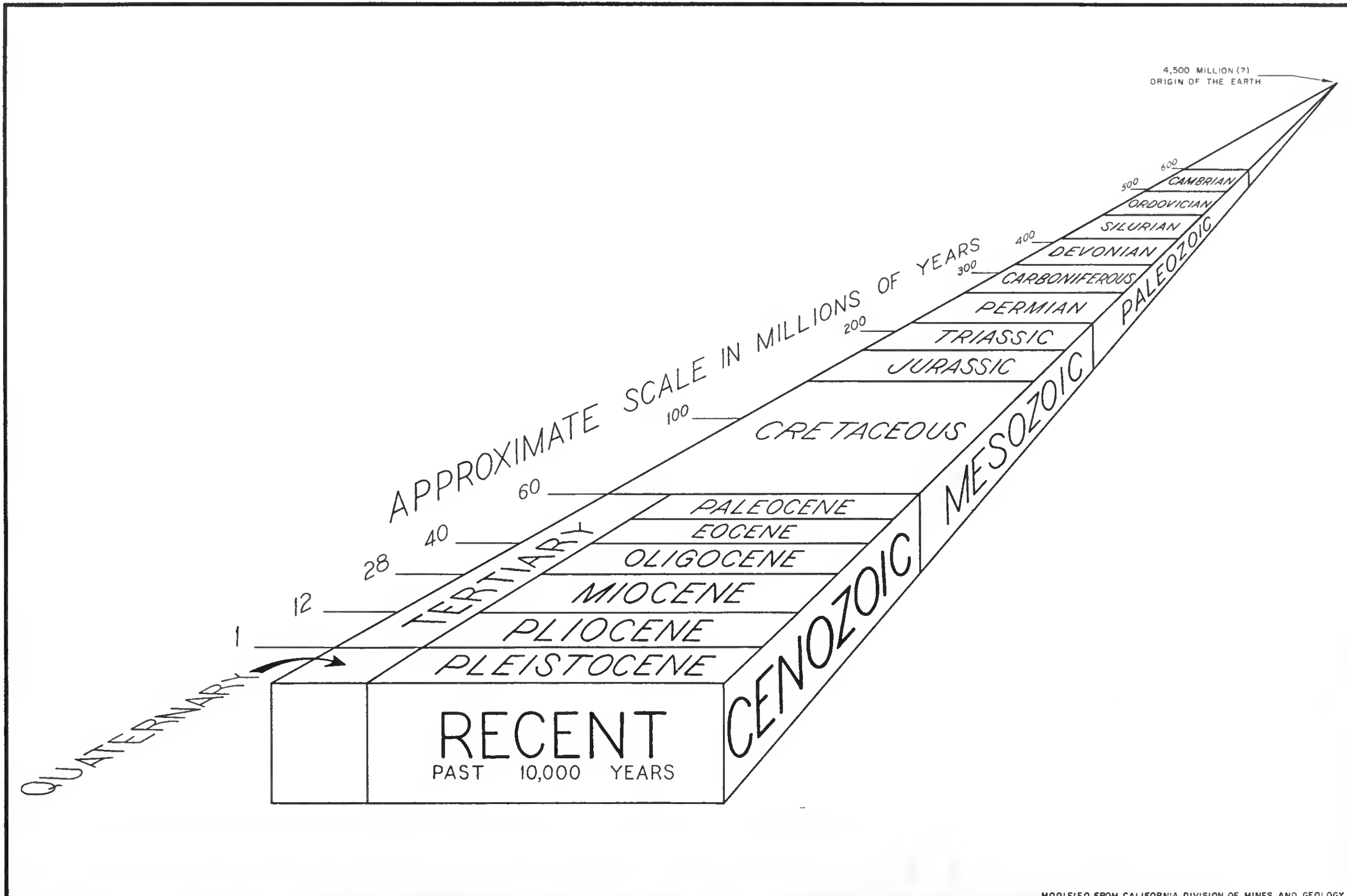


Figure 6. LOOKING BACK IN GEOLOGIC TIME

outbursts of volcanic activity, building of mountain ranges, or the rising or sinking of the land, coupled with the retreat or advance of the sea. The three eras have been subdivided into eleven periods ranging from the oldest Paleozoic period, the Cambrian, to the youngest Cenozoic period, the Quaternary. The two most recent periods, the Tertiary and the Quaternary, have been further subdivided into seven epochs. These epochs range from the oldest, the Paleocene, to the youngest, the Recent, which is the epoch within which we now live.

In the early part of the Paleozoic era, what is now Northeastern California was covered by a part of the ocean. During the next 200 million years, up to the beginning of the Mesozoic era, the land was periodically above sea level where it was the location of volcanoes and lava beds. At other times during this interval, the land sank and was the bottom of the ocean.

In the Mesozoic era, the crust of the earth began to shift due to the intrusion of an immense mass of rock under tremendous heat and pressure. This rock mass, moving upward from the bowels of the earth, buckled the overlying rock. This formed a rugged, snow-capped range located in the same general area as the Sierra Nevada. The relentless forces of erosion working for 100 million years succeeded in wearing down all of this mountain range to produce a series of low rolling hills bordered on the west by the sea. This was the picture of Northeastern California at the close of the Mesozoic era, some 60 million years ago.

The Cenozoic era was ushered in by renewed volcanic activity and a rebuilding of extensive mountain ranges. By the beginning of the Miocene

epoch, 32 million years of volcanic and mountain-building activity again had been nearly obliterated by the forces of erosion. What was left was a region of rolling hills separated by valleys and lakes. The hills were cloaked with forests of ginkgo, oak, madrone, plum, and many other types of trees and shrubs not now native to the area. In the area that is now Nevada, there was a high mountain range covered by forests of fir and pine. Here and there, groves of giant redwoods flourished. The climate, too, was different from that of today, for Northeastern California was a subtropical region, warm and rainy like Florida.

The beginning of the Pliocene epoch was signified by renewed movement of the crust of the earth. The Warner Mountains, the Diamond Mountains, and volcanoes such as Snowstorm Mountain, were constructed during this epoch. At the same time, many of the lakes increased in size to approximately the size of the present Great Lakes in eastern North America. The climate changed somewhat, and the forests became composed entirely of hardwoods such as maple, madrone, poplar, and oak. Animal life also changed, and camels, horses, bison, and elephant-like mastodons roamed the grassy areas.

The Pleistocene epoch was the time of the four stages of the Ice Age. Each stage lasted up to 100,000 years, during which time the climate was cold and stormy. Between the glacial stages, there were three interglacial stages lasting from 125,000 to 275,000 years. These latter stages were characterized by a hot, dry climate much like that of today. In fact, today's post-glacial stage dates back only about 15,000 years.

During each glacial stage, deep snows mantled the mountains and created slow-moving glaciers. These rivers of ice sculptured the mountains into sharp peaks and U-shaped valleys. The rock which was quarried from

the mountains was deposited in the lowlands as moraines. By the middle of each glacial stage, many of the lakes attained enormous size. In fact, during the most recent glacial stage, one lake, Lake Lahontan, stretched from Honey Lake Valley east and south to Walker Lake in Nevada, a distance of about 300 miles. Plant and animal life was, perhaps, similar to that found today in colder, wetter climates. During the interglacial stages, the land slowly returned to a desert climate and many of the lakes dried up, only to reappear once again during the next glacial stage. Volcanic activity continued sporadically all during this time and resulted in the young lava flows found in certain parts of the region. The recency of some of this activity is shown by the rough, barren surface of some lava flows.

During the last 10,000 years, the climate has slowly become warmer and drier. The glaciers were the first to disappear, followed by most of the lakes that once filled the valleys. The few lakes that remain today are mostly mere remnants of the ancient lakes.

Today, the ever-active forces of erosion are slowly wearing down the mountains and filling in the valleys as they have done in all ages past. In addition, movements of the earth's crust are still slowly pushing up the mountains and dropping the valleys as shown by the earthquakes in historical times. Evidence of recent volcanic activity is illustrated by a 200-year old lava flow found in Lava Beds National Monument and the 1914 eruption of Lassen Peak.

Each of the ground water basins investigated has a known geologic history dating back to about the Pliocene epoch. A brief account of the history of each basin is given in Chapter IV.

Geologic Formations of Northeastern California

The following section discusses the geologic formations of Northeastern California. Included in the discussion is a brief description of each geologic unit outcropping in the area of investigation. The description includes general statements on the physical and water-bearing properties of each unit. More specific information regarding the ground water geology of the particular basins studied is presented elsewhere in this bulletin.

Basement Complex Rocks

Basement complex rocks are present at the surface in about five percent of the area investigated. The rocks are of Paleozoic to Mesozoic age and are found on the surface generally to the south and southwest of Honey Lake Valley. The rocks of this group do not ordinarily yield usable quantities of ground water. However, springs occurring along faults may provide small quantities of water for stock and domestic uses. In addition, some water occasionally may be obtained from joints or weathered zones. The rocks of this group are divided into metamorphic rocks and granitic rocks, each of which is described below.

Metamorphic Rocks (pKm). Metamorphic rocks outcrop west of Willow Creek Valley and in the vicinity of Sierra and Mohawk Valleys. The rocks consist of quartzite, slate, and metamorphosed andesite and rhyolite, all of pre-Cretaceous (Silurian through Jurassic) age. Metamorphic rocks are essentially impermeable and of little importance to ground water.

Granitic Rocks (JKgr). Granitic rocks ranging from granodiorite to diorite in composition are found in the same general area as the metamorphic rocks. These rocks are generally very massive, impermeable, and of little importance to ground water. A few areas of granitic rocks are deeply

weathered and decomposed. The decomposed granitic rocks are of appreciable but low permeability and may provide small quantities of ground water to wells or sumps.

Volcanic Rocks

The volcanic rocks are of Eocene to Recent age and are found throughout Northeastern California where they make up about 65 percent of the land surface. The rocks of this group generally overlie basement complex rocks. The volcanic rocks include a variety of lavas which range in composition from rhyolite to andesite and basalt; also included are various types of pyroclastic rocks. The permeability of the volcanic rocks is highly variable and ranges from very high in the Recent basalt flows to exceedingly low in certain andesites and pyroclastic rocks.

Sierran Volcanic Rocks (Tsv, Tsvb, Tsva, and Tsvp). The Sierran volcanic rocks consist of a series of lavas and pyroclastic rocks ranging in age from Eocene through Miocene. These rocks occur in the region from Honey Lake Valley southward beyond Sierra Valley.

Sierran basalt (Tsvb) frequently occurs at higher elevations, such as at the summit of Thompson Peak where it is about 1,000 feet in thickness. The basalt appears to be in part highly permeable due to open joints and scoria zones. Because the basalt is usually above the zone of saturation, it is of little importance to ground water. Certain areas of this basalt may, however, contain small quantities of ground water which could locally supply domestic or stock-watering needs.

Sierran andesite (Tsva) occurs as massive to platy plugs and flows, notably at Sugar Loaf in Sierra Valley. It is essentially impermeable and is unimportant to ground water.

Sierran pyroclastic rocks (Tsvp) consist of mudflows and tuffs that are all essentially impermeable and consequently of no importance to ground water.

Cedarville Series (Tmc). The Cedarville series of Miocene age outcrops along the Warner Mountains and Hays Canyon Range. It is suspected that the series also occurs at depths of several thousand feet beneath Goose Lake Valley, Surprise Valley, and the Alturas Basin.

The Cedarville series is composed of about 7,500 feet of bedded tuff, tuff breccia, and a few basalt and andesite flows. Interbedded within the series are a few sills of younger rhyolite. All of the rocks of the Cedarville series are nearly impermeable. Consequently, the series is relatively unimportant as a source of ground water.

Turner Creek Formation (Tmtc). The rocks of the Turner Creek formation are found in the mountainous area between Warm Springs Valley and Big Valley. These rocks are composed principally of Miocene mudflows and tuff, but they also contain lesser amounts of basalt flows and interbedded sandstone, conglomerate, and diatomite. The Turner Creek formation is about 4,000 feet thick and may be correlative with the upper part of the Cedarville series. The Turner Creek formation probably exists at depths beneath the Alturas Basin and Big Valley, where it grades upward into lake sediments of Pliocene and Pleistocene age.

The Turner Creek formation is not considered to be a good source of ground water. However, there appear to be local beds of sand and gravel which are sufficiently permeable to yield moderate quantities of ground water to wells.

Big Valley Mountains Volcanic Series (Tvb). The Big Valley Mountains are composed of a thick series of basalt flows and minor beds of sand, tuff,

and diatomite. The series is of Miocene to Pliocene age, may be as much as 4,000 feet thick, and may be correlative in part with the previously described Turner Creek formation. The upper portion of the series is composed of about 400 feet of basalt which has a uniform easterly dip, suggesting that it may extend beneath the floor of Big Valley where its depth would be several thousand feet.

The Big Valley Mountains volcanic series has a low overall permeability. Hence, it is considered to be of little importance to ground water. However, there may be local permeable zones which could yield sufficient water for domestic or stock purposes.

Miocene Volcanic Rocks (Tmv, Tmvb, Tmva, Tmvp). Miocene volcanic rocks occur in many areas north of Madeline Plains. In most of the areas studied, the Miocene volcanic rocks have been divided into basalt, andesite, and pyroclastic rocks.

The Miocene basalt (Tmvb) is a dark-colored lava containing occasional fracture and scoria zones. It frequently occurs as tilted lava plateaus up to several hundred feet in thickness. The basalt is found along the crest of mountains, such as at Eagle Peak, and also at low areas such as along the east side of Surprise Valley, thus indicating a great amount of fault movement since the basalt flows were emplaced. Areas of Miocene basalt frequently have a number of faults crossing them. These faults may interrupt the continuity of the fracture and scoria zones, thus affecting the flow of ground water along these zones. In general, the Miocene basalt ranges from low to moderate permeability. Where located within the zone of saturation, it may yield moderate amounts of water to wells.

Miocene andesite (Tmva) occurs in the Warner Mountains and at a few other localities. It is more massive than the basalt as it frequently occurs as short, stubby flows or as plugs and domes. As it is relatively impermeable, it is of little significance to ground water.

Miocene pyroclastic rocks (Tmvp) outcrop to the northeast of Madeline Plains and also in the Warner Mountains. The rocks may be correlative to similar rocks found in the Turner Creek formation and consist of dark-colored mudflows and beds of pale-colored tuff. Included in this group are a few beds of sandstone and diatomite. In general, the Miocene pyroclastic rocks are of low permeability and thus of little importance to ground water. Some of the sandstone beds, however, may be sufficiently permeable to provide limited amounts of ground water to domestic or stock wells.

Rhyolite (Tvr). Rhyolite of Miocene to Pliocene age has a widespread distribution in the area studied; however, the total area of rhyolite outcrops is quite small. The rhyolite is a pale-colored, massive to jointed rock; it occasionally contains zones of black to brown obsidian. The rock usually occurs as plugs and domes, but on occasion may occur as sills within older rocks. As rhyolite is essentially impermeable, it is of little importan to ground water.

Pliocene Volcanic Rocks (Tpvb, Tpva, Tpvp). Pliocene volcanic rocks occur north and west of Willow Creek Valley. The Pliocene volcanic rocks are divided into basalt, andesite, and pyroclastic rocks.

Pliocene basalt (Tpvb) is gray-black in color and contains a few permeable scoriaceous zones along the top and bottom of individual flow units. In addition, the basalt also contains some vertical joints which form permeable paths connecting the various scoriaceous zones and render the basalt moderately permeable. Some of the precipitation falling on the

basalt seeps downward along the joints and then moves laterally along the scoriaceous zones. Pliocene basalt, where sufficiently recharged, yields moderate quantities of ground water to wells.

Pliocene andesite (Tpva) occurs at widely separated areas as plugs and short, stubby flows. The rock is massive to platy, essentially impermeable, and unimportant to ground water.

Pliocene pyroclastic rocks (Tpvp) consist of mudflows and beds of tuff. The rock is quite massive, essentially impermeable, and of little importance to ground water.

Plio-Pleistocene Volcanic Rocks (TQvb, TQvp). Basalt and tuff of Plio-Pleistocene age occur in widely separated areas from Honey Lake Valley north to the Oregon state line. The basalt (TQvb) makes up the cones of old Plio-Pleistocene volcanoes such as Snowstorm, Shinn, Shaffer, and Tule Mountains. It also occurs as sloping plateaus in the Alturas Basin and in Goose Lake Valley. In the latter area, the basalt is about 500 feet in thickness. Individual flows in the basalt range from 10 to 80 feet in thickness, and are separated by highly permeable zones of scoria up to 20 feet in thickness. Each flow has been broken by joints and fractures caused by cooling of the lava and by folding and faulting. Occasional beds of silt, clay, diatomite, and tuff up to 50 feet in thickness are also present.

The breaking and fracturing of the basalt flows and the presence of scoria zones have resulted in the creation of many permeable paths for ground water movement. Much of the precipitation which falls on the Plio-Pleistocene basalt seeps downward and laterally toward the sediments in the adjacent valley areas. Ground water movement in the basalt is illustrated in Figure 7. The basalt is moderately to highly permeable and where sufficiently recharged probably would yield moderate to large quantities of water to irrigation wells. In areas where the basalt flows are interbedded with

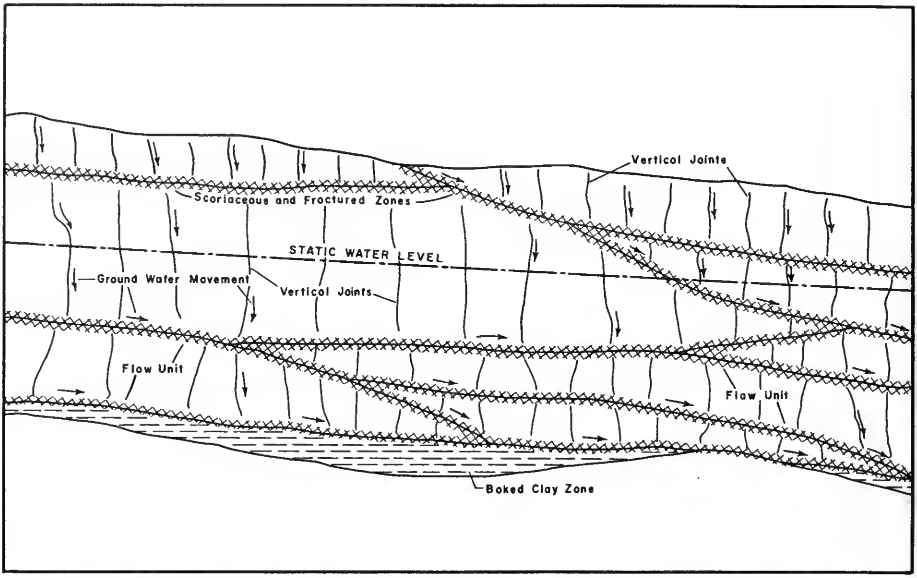


Figure 7. DIAGRAMMATIC SECTION OF TYPICAL BASALT FLOW

less permeable valley sediments, the basalt contains confined ground water. Irrigation wells tapping these buried lava flows may yield large quantities of ground water.

Minor areas of Plio-Pleistocene tuff (TQvp) occur in a few basins. It is of little importance to ground water.

Warm Springs Tuff (TQvt). Extensive Plio-Pleistocene pyroclastic rocks occur in the Alturas Basin, and are named herein the Warm Springs tuff member of the Alturas formation. The rock is made up of a sequence of from 100 to 400 feet of gray to brown, massive pumice lapilli tuff, light-colored ashy sandstone, and resistant rimrock areas formed by basalt-like welded tuff. One of the distinguishing characteristics of the Warm Springs tuff is the numerous chimney rocks caused by weathering of the massive ash flow tuff.

In general, the permeability of the Warm Springs tuff is fairly low; hence, it would not yield large quantities of water to wells. However, some of the sandstone beds and zones of fractured, welded tuff, where sufficiently recharged, may provide moderate quantities of water to domestic or stock wells.

Pleistocene Volcanic Rocks (Qpvb, Qpvp). Pleistocene volcanic rocks are found in the vicinity of every major valley in Northeastern California. The dominant rock type is basalt (Qpvb), which occurs as lava plateaus and ancient volcanoes. The most typical plateau is the Devils Garden area northwest of Alturas. This immense plateau is composed of a great number of Pleistocene lava flows ranging in total thickness from 50 to over 200 feet. The Devils Garden lavas are composed of dark-colored olivine basalt. The basalt blankets most of the area west and southwest of Goose Lake Valley, and extends westward about 40 miles nearly to Lava Beds National Monument, where it is overlain by basalt flows of Recent age.

Faulting has broken the Devils Garden basalt into many tilted blocks separated by nearly vertical scarps ranging in height from 10 to 100 feet. Many of the fault zones are highly permeable and provide paths for the downward movement of precipitation to the ground water body. In addition, the Devils Garden basalt contains numerous open joints and fractures which also serve as passageways for the downward migration of ground water.

Pleistocene lavas are also present at certain extinct volcanoes. One is Heavey Mountain near Madeline Plains. The lavas at this and other extinct Pleistocene volcanoes have similar characteristics to the previously described Devils Garden basalt.

In general, the Pleistocene basalt is moderately to highly permeable. In some areas, ground water in this rock may be at a depth of over 200 feet.

In other areas, springs indicate the presence of near-surface ground water. In places where Pleistocene basalt flows have been buried by fine-grained valley sediments, the basalt acts as an excellent aquifer. Under these conditions, it may yield large quantities of confined ground water to irrigation wells.

Pleistocene pyroclastic deposits (Qpvp) occur as beds of permeable cinders and tuff or as impermeable mudflows. The pyroclastic materials are of small areal extent, and where permeable, serve only as catchment areas for the recharge of ground water to adjacent and underlying materials. The cinders and tuff are only locally significant as sources for domestic or stock water.

Cinder Cones ( ). Pleistocene and Recent cinder cones occur near Fall River Valley, Eagle Lake, Madeline Plains, and Warm Springs Valley. The cones consist of moderately permeable, semi-consolidated red-to-black volcanic cinders. As they are situated above the zone of saturation, they do not contain usable ground water.

Recent Basalt (Qrvb). Ropy and clinkery basalt flows of Recent age occur near Fall River Valley and near Eagle Lake. The lavas north of Fall River Valley are typical of the Recent basalt. These flows are highly jointed and vesicular. They have an areal extent of at least 500 square miles and apparently originated in part from vents and fissures located on the slopes of the Medicine Lake Highlands. The Recent lavas are 30 to 40 feet thick along their margins and may be up to 500 feet or more in thickness in areas of greatest accumulation.

The rough, vertically jointed, irregular surface of the Recent basalt readily permits the downward percolation of precipitation, as the

rocks are extremely permeable and transmit and store large quantities of ground water. Stream channels or other evidence of appreciable surface runoff are typically absent. The Recent basalt provides copious quantities of water to springs, streams, and lakes at the north end of Fall River Valley.

Sedimentary Deposits

Sedimentary deposits comprise about 30 percent of the surface materials in Northeastern California. They are found in all valley areas and range in composition from hard sandstone and shale to unconsolidated gravel, sand, and clay. The age of the sediments ranges from Eocene to Recent. Their permeability is widely variable, ranging from exceedingly low to very high.

Fort Sage Sandstone (Tfs). A hard, consolidated sandstone outcrops along the western side of the Fort Sage Mountains. This sandstone, named herein the Fort Sage sandstone, is of early Tertiary age and of unknown thickness. The rock is generally massive but contains a few widely spaced joints. It is essentially impermeable; however, there may be a few zones which could yield small quantities of water to wells.

Gold Run Sandstone (Tgs). A semi-consolidated, poorly cemented sandstone and shale occurs along Gold Run Creek. This sandstone, named herein the Gold Run sandstone, is of early Tertiary age and of unknown thickness. The permeability of the Gold Run sandstone appears to be low. However, it may yield small amounts of water to wells.

Auriferous Gravels (Teg). River gravel deposits of Eocene age occur in the mountainous area southwest of Honey Lake Valley. The deposits are of low to moderate permeability and consist of semi-consolidated gravel, sand, and clay, in part gold-bearing. Auriferous gravels yield small amounts of ground water to many springs, but because the deposits are located only at higher elevations, they are unimportant to ground water in Honey Lake Valley.

Deep Creek Conglomerate (Tødc). A conglomerate of Oligocene to Miocene age outcrops along the western side of Surprise Valley, at the foot of the Warner Mountains. The conglomerate, named herein the Deep Creek conglomerate, is composed of westward-dipping beds of massive, consolidated conglomerate separated by beds of shale, mudflows, and tuff. The rocks are essentially impermeable and of little importance to ground water.

Forty-Nine Camp Formation (Tmfc). The only recognized outcrops of the Forty-nine Camp formation are to the northeast of Surprise Valley. The formation consists principally of Miocene sandy tuff and volcanic gravel. It may be a sedimentary phase of the more widespread Cedarville series. In its outcrop area, the Forty-nine Camp formation is about 750 feet thick and dips gently to the west. It is overlain by Miocene basalt flows.

Certain beds of the Forty-nine Camp formation appear to be moderately permeable and may provide moderate quantities of ground water to irrigation wells. Recharge to the Forty-nine Camp formation is from precipitation falling on the area between Surprise Valley and Long Valley in Nevada.

Pliocene Lake Deposits (Tpl). Bedded lake deposits of Pliocene age outcrop in Honey Lake Valley, Secret Valley, and several other valleys. The greatest accumulation is in Honey Lake Valley, where the deposits are nearly 5,000 feet thick.

The Pliocene lake deposits generally consist of bedded consolidated sandstone, siltstone, and diatomite. The deposits in the various valleys are probably of equivalent age, having been deposited during the Pliocene epoch.

The water-bearing characteristics of the Pliocene lake deposits are largely unknown. It appears that the deposits in general possess only low to moderate permeability and thus would be able to provide only relatively small to moderate quantities of confined ground water for limited irrigation purposes. The deposits usually should provide sufficient water for domestic or stock purposes. A few areas of Pliocene lake deposits are composed of near-shore sand and gravel. These latter areas could provide somewhat greater amounts of ground water for irrigation purposes.

Alturas Formation (TQa). Plio-Pleistocene lake deposits in the Alturas Basin belong to the Alturas formation. The formation consists of two nearly identical sedimentary members separated by a Plio-Pleistocene basalt member and the Warm Springs tuff member. The lower and upper sedimentary members consist of flat-lying, light-colored sandstone, gravel, diatomite, and tuff, having a total thickness of about 800 feet. The lower member is believed to be underlain by basalt and rocks of both the Turner Creek formation and the Cedarville series.

The lower and upper members of the Alturas formation are the principal water-yielding materials in the Alturas Basin. Beds within the two members range in permeability from moderate to high, contain both semi-confined and confined water, and provide abundant water to irrigation wells.

Bieber Formation (TQb). Most of the lake deposits in Big and Round Valleys belong to the Bieber formation of Plio-Pleistocene age. These deposits are composed of interbedded gravel, white sand, black sand, clay, silt, and diatomite. They are estimated to be at least 1,000 feet thick and are probably underlain by similar materials belonging to the Turner Creek formation.

The Bieber formation is moderately permeable and yields moderate amounts of ground water to numerous domestic and irrigation wells. The best producing zones appear to be the white sands and the black sands. However. the main difficulty in developing the sand zones is that they are usually very thin and are separated by less permeable zones of clay, silt, and diatomite.

Moraines (Qpm). During the Pleistocene epoch, huge masses of ice covered the crest of the Sierra Nevada and the Warner Mountains. These slowly moving glaciers carved broad basins into the rock. The Lakes Basin in the Sierra Nevada is an example of such a glacial-carved feature, and today it gives mute evidence of the relentless grinding and polishing action of the glaciers.

The great volumes of rock that were removed from the mountains were transported by the glaciers downslope. When the glaciers melted, they dropped their rock loads in the form of moraines. These moraines are exposed today along the west side of Mohawk Valley, and at scattered localities in the Warner Mountains. The moraines are composed of a slightly consolidated mixture of boulders, cobbles, sand, and rock flour. Permeability of the moraines is generally low; however, a few springs issue from the deposits confirming the presence of a few permeable zones.

Glacial Outwash (Qpo). While the glaciers were melting, great torrents of water were cascading down the mountains carrying rocks and sand into the adjacent valleys. This material formed the outwash deposits that are now found along the west side of Mohawk Valley. These outwash deposits appear to be moderately permeable and locally may yield moderate amounts of ground water to wells. A few zones in the outwash deposits are probably highly permeable and may yield large amounts of ground water to wells.

Pleistocene and Lahontan Lake Deposits (Qpl). Lake deposits of Pleistocene age are found in Fall River Valley, Madeline Plains, and the Sierra Valley-Mohawk Valley area. Lake deposits also occur in Honey Lake Valley where they are called Lahontan Lake deposits.

The Pleistocene lake deposits are made up of bedded blue-gray silt, clay, and lesser amounts of sand. The deposits may be up to several thousand feet thick. Interbedded with the materials are a few lava flows and occasional beds of diatomite and volcanic ash. Most of the lake deposits probably grade downward to older lake deposits of Pliocene age.

Moderate permeabilities are characteristic of the Pleistocene lake deposits in Fall River Valley and Madeline Plains. This, along with the presence of alkali and high concentrations of dissolved salts in the ground water, frequently makes the deposits in these areas of little direct value as a source of ground water. Pleistocene lake deposits in Sierra and Mohawk Valleys are moderately to highly permeable and yield moderate to large quantities of water to wells.

In Honey Lake Valley, Pleistocene lake deposits were formed on the bottom of Lake Lahontan. These deposits, although generally similar to the previously described Pleistocene lake deposits, have extensive sandy zones that are moderately to highly permeable. Consequently, these deposits constitute the most important aquifer in Honey Lake Valley. The Lahontan lake deposits often provide large quantities of water to wells located in the southeastern and northwestern portions of Honey Lake Valley.

Near-Shore Deposits (Qps). Near-shore deposits, of Pleistocene age, frequently are associated with both the Pleistocene and the Lahontan lake deposits. The near-shore deposits were formed at the same time as the lake deposits and differ from them only in composition and permeability. The two types of deposits generally interfinger.

Near-shore deposits were formed along beaches, terraces, and deltas surrounding the lakes which once occupied the valleys. The deposits consist of bedded, poorly consolidated gravel, sand, silt, and clay. They are usually not over 300 feet in thickness, but they may extend laterally beneath the lake deposits to the lowest point in the bedrock floor of the valley where they may be several thousand feet thick.

The near-shore deposits generally are of moderate to high permeability. The presence of occasional cemented zones and beds of silt and clay tend to confine ground water to certain more permeable beds. In general, where the near-shore deposits are within the zone of saturation, they yield fair to moderate to large quantities of ground water to irrigation wells.

Terraces (Qt). A few lake and stream terraces are located in Goose Lake Valley and Mohawk Valley. These deposits are of Pleistocene to Recent age and are probably not over 50 feet in thickness. The terraces are composed of poorly sorted gravel, sand, silt, and clay. Because of their small areal extent and moderate permeability, the terraces are only capable of yielding moderate quantities of ground water to shallow domestic and stock wells.

Alluvial Fans (Qf). Alluvial fans of Recent age have formed at the mouths of many canyons entering the valleys of Northeastern California. The fans are composed of stratified gravel, sand, and silt, and in some cases may be as much as 1,000 feet in thickness. The alluvial fans frequently contain the principal aquifers in a valley. These aquifers are capable of yielding large quantities of confined and semi-confined water to wells. Alluvial fans also are important as recharge areas. This is demonstrated by the high permeability of the upper, bouldery portions of the fans. Wells located here may yield large quantities of unconfined ground water even

though the water table may be fairly deep. The middle portions of the fans consist of a sandy and gravelly zone that is somewhat less permeable, but still could act as a recharge area to a lesser degree. Wells located in this middle zone may encounter moderate to high quantities of both unconfined and confined water. The beds in this zone of the fan are discontinuous. Thus, there is no certainty of finding a permeable bed at a specific point and specific depth. The lowermost portion of the fans are usually somewhat less permeable but may contain permeable sand beds which could yield confined water. Like the middle zone, however, the beds in this lower zone also may be discontinuous. Hence, for this zone too, there is the uncertainty of intercepting beds at a specific location or depth. Figure 8 shows a longitudinal section along a typical fan and delineates the three water-bearing zones.

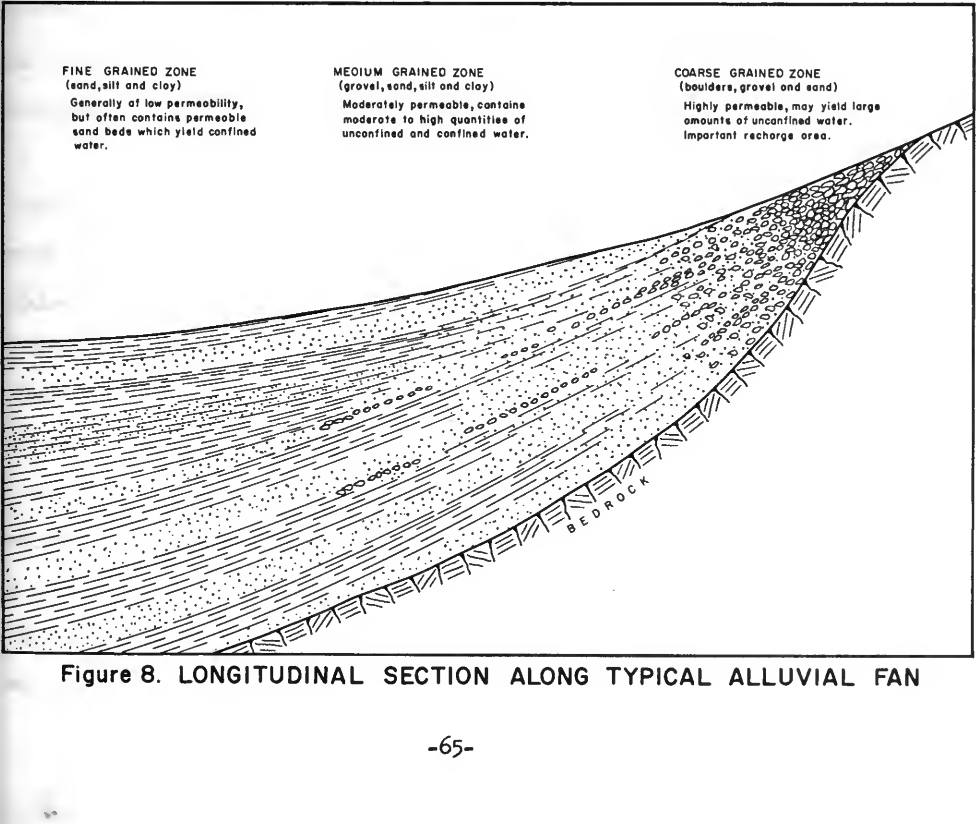


Figure 8. LONGITUDINAL SECTION ALONG TYPICAL ALLUVIAL FAN

Intermediate Alluvium (Qal). The toe areas of alluvial fans merge into alluvial plains composed of intermediate alluvium of Recent age. The alluvium generally consists of unconsolidated sand and silt with some lenses of gravel and clay. It is usually not over 100 feet in thickness. In general, the intermediate alluvium is only moderately permeable; however, lenses of coarse material are present which are capable of providing good quantities of ground water to shallow irrigation wells.

Basin Deposits (Qb). Basin deposits of Recent age occur in the flat, central portions of many valleys. The deposits consist of unconsolidat silt, clay, organic muck, and a few thin layers of fine sand. Some alkali ma be present. The basin deposits are usually not over 100 feet in thickness. The permeability of the basin deposits is generally low and hence they yield only small amounts of water to shallow domestic and stock wells.

Muck and Peat Deposits (Qmp). Organic muck and fibrous peat occur in Jess Valley. The deposits are of Recent age and are currently being mined as a source of agricultural peat. The deposits are of very low permeability and of no importance to ground water.

Talus (Qta). Accumulations of unconsolidated rubble form wedge-shaped talus slopes at the bases of many steep fault scarps along Pit River. These talus deposits, along with the fault zones with which they are related, provide vertical paths which may effect recharge of deep aquifers within adjacent sediments. Because the talus deposits are small in areal extent and are mostly located above the water table, they are considered to be of minor importance as a direct source of ground water.

Landslides (Qls). Large landslides, of Recent age, have occurred at a few localities. The slides usually consist of a mixture of rubble, clay sand, and crushed rock. Landslides are generally of low permeability and unimportant to ground water. However, the landslides along the north side

of Honey Lake Valley appear to be moderately permeable and locally yield moderate amounts of ground water to wells.

Recent Lake Deposits (Ql). Recent lake beds are found at Goose Lake, Eagle Lake, Honey Lake, the three alkali lakes in Surprise Valley, and at numerous other localities. The deposits consist of sticky, blue-black silt, clay, and organic muck; they also contain occasional stringers of salt, alkali, and fine sand. These lake deposits range in thickness from a feather edge to a possible maximum thickness of about 5,000 feet. While the deposits are of Recent age near the surface, many of them are probably Pleistocene and older in age at a depth greater than 100 feet.

The overall permeability of the Recent lake deposits is very low. As a consequence, they apparently serve as a barrier to both vertical and horizontal ground water movement. Furthermore, alkali, salt, and organic matter adversely affect the quality of any ground water that is contained in these deposits. Hence, the lake deposits are not considered to be a source of either appreciable quantities or good quality ground water.

Sand and Silt Deposits (Qs). Recent wind blown accumulations of sand and silt form a widespread mantle over the alluvial fans, basin deposits, and lake deposits in portions of Surprise Valley, Honey Lake Valley, and Sierra Valley. The deposits are moderately to highly permeable, but because they are at most only about 20 feet in thickness and are located above the water table, they do not contain any great amounts of water.

Sand Dunes (Qsd). Scattered areas of Recent sand dunes occur along the east side of Surprise Valley, at the south end of Goose Lake, at the east end of Madeline Plains, and on the west shore of Eagle Lake. The dunes range from 6 to 30 feet in height and are composed of unconsolidated beach sand. The dunes are highly permeable, but being situated above the water table, contain little water.

CHAPTER IV. GROUND WATER

Ground water in amounts needed to provide for existing and probable future requirements for domestic and stock use can be obtained in all ground water basins investigated. Significant potential for economic development of ground water in sufficient quantities for irrigation purposes exists in portions of all the ground water basins evaluated. Preliminary evaluations of the potential for ground water development for each ground water basin and a discussion of the various factors involved are included in this chapter.

A brief description of the physical features of each ground water basin and subbasin is presented. The more important topographic features of each basin are also described along with comments pertaining to the surface water drainage systems found within each basin. A brief geologic history of each individual basin points out the similarities and differences in the processes which formed the several valleys.

In this chapter, only the principal water-bearing formations found in each ground water basin are discussed. (However, all of the geologic formations found in the northeastern counties are included in the foregoing discussion starting on page 50.) Plates, figures, and tables concerning the ground water geology of each basin are also presented and explained. The influence of geologic structure on the occurrence and movement of ground water is also set forth for each basin investigated.

Plates showing generalized lines of equal elevation of water in wells were prepared for conditions as they existed in the Spring of 1960 for all but two of the ground water basins investigated. These plates are found under separate cover but are discussed in this chapter. Plates showing lines of equal elevation of water in wells could not be prepared for Secret and Humbug Valleys because well data were unavailable for these valleys.

The lines of equal elevation for the several basins reflect either confined or unconfined ground water conditions or combinations of the two conditions. The absence of lines of equal elevation on portions of any of the plates should not be construed to indicate that no ground water is present. Existing wells and known recharge areas are in some instances widely separated, but it is reasonable to assume the existence of ground water in the intervening areas, even though data were insufficient to warrant the drawing of lines of equal elevation for the area. In some instances inferred lines are drawn to indicate the presence of ground water. The location of these inferred lines is based on all related data and engineering judgment.

In the basins where generalized lines of equal elevation of water in wells in confined aquifers have been prepared, the lines indicate the elevation to which water would rise in a well supplied by the confined aquifer. The elevations of the water in such wells or the surface formed by such lines is also called the piezometric surface. Where the piezometric surface is above the ground surface, water in a well would flow without pumping. Areas where the piezometric surface is above the ground level have been indicated on the plates.

Under the heading "Recharge and Movement of Ground Water," the upland recharge areas and the probable pattern of ground water movement are discussed. The recharge within the valley floor area is discussed only when of particular significance or when explaining the source of supply to certain aquifers. Precipitation during the period covered by this investigation has been significantly below the average for the area. The evaluations of potential for development discussed in the next paragraph are based upon the assumption of more nearly average conditions of precipitation. The evaluations of ground water movement are based primarily on the generalized

lines of equal elevation of water in wells discussed in the preceding paragraphs. Field observations as well as engineering judgment also play a part in reaching the conclusions presented. The patterns of movement described are believed to be reasonably accurate for existing knowledge of the ground water within the several valleys. Future development of wells in some limited areas may alter present patterns of ground water movement and could result in local changes that might reduce the yield to some adjoining wells.

The present use of ground water is briefly described for each of the ground water basins. The total amount of pumpage, however, was unknown and available data were insufficient to warrant the making of estimates of total use. The acreages irrigated from ground water are indicated whenever such data are available. Yields of some of the wells are also presented to indicate the yield available in certain locations and formations.

Four classifications of potential for development of ground water were established, namely:

"A" Zone: Best areas for development of ground water.

Properly constructed wells located in "A" Zone areas should yield sufficient quantities of ground water for irrigation purposes.

"B" Zone: Good areas for development of ground water.

Properly constructed wells located in "B" Zone areas should yield sufficient quantities of ground water for most irrigation purposes. Yields generally will be somewhat less than in "A" Zone areas.

"C" Zone: Fair areas for development of ground water.

Properly constructed wells located in "C" Zone areas may yield sufficient quantities of ground water for limited irrigation purposes. Yields should be sufficient for domestic and stock-watering purposes, but generally will be substantially less than in "A" or "B" Zone areas.

"D" Zone: Poor areas for development of ground water.

Properly constructed wells located in "D" Zone areas may yield sufficient quantities of ground water for domestic or stock-watering purposes. The possibility of dry holes is much greater in "D" Zone areas than in other areas.

Plates showing the areas in each zone for each ground water basin summarize the conclusions as to potential for quantitative development of ground water. Classification of each area is based upon interpretations of the data regarding geology, precipitation, and ground water.

A brief summary of the mineral quality of ground water within each ground water basin is presented. Known hazards due to poor quality water are pointed out in the text and areas of hazard are prominently indicated on the plates showing potential for development of ground water.

Under the subheading "Concluding Remarks and Recommendations" comments appropriate to each specific ground water basin are set forth. This investigation has attempted to collect, integrate, and evaluate all available data in order to develop and present a generalized opinion of the ground water development potential within certain ground water basins located in Northeaste California. It is realized that some of the details of this opinion are of a preliminary nature and should be revised as additional data are obtained. It is believed that this bulletin and particularly the evaluations presented in this chapter, provide a foundation which will aid in making decisions concerning the development of additional ground water supplies. In the attempt to integrate and evaluate the available data, the need of additional informati became quite apparent. Some of this needed information could be obtained from new wells, while other information necessitates records to be collected over long periods of time. Certain information can be obtained only by specialized geologic and hydrologic investigations. Thus, if a more reliable opinion is required concerning the ground water development of these basins, the

department's continuing data collection activities should be supplemented by specialized programs to obtain all the data needed.

Throughout the text, the use of wells of usual construction for developing ground water is frequently referred to. There is another method by which near-surface ground water has been developed for stockwatering and limited irrigation use within certain portions of the area of investigation. This method involves the excavation of sumps to intercept the near-surface ground water. The yield from sumps is usually lower than the yield of good irrigation wells, but their cost is many times lower. The operation of a sump for irrigation use can be accomplished without interfering with its continued use for livestock. There are some locations in most of the basins in the northeastern counties where this method of ground water development seems feasible. A high water table within permeable deposits is the major prerequisite for this type of ground water development. However, it must be realized that incorrect location, a severely fluctuating water table, local overdevelopment of ground water, or a prolonged drought may severely restrict the potential yield of such an installation.

Goose Lake Valley Ground Water Basin

This investigation concerns itself only with the California portion of the Goose Lake Valley ground water basin, although a considerable portion of the basin lies in southern Lake County, Oregon. Goose Lake Valley, about 47 miles long by 12 miles wide, extends into Oregon from northern Modoc County. From the Fremont Mountains to the north and the Warner Mountains to the east, several streams flow into the valley and enter Goose Lake. The bed of the lake covers a large portion of the valley, particularly in California. The bed lies at elevation 4,692 feet and was exposed in the early 1930's when the lake was dry. In the extreme southerly portion of the basin, streams flow into North Fork Pit River rather than into the lake, although in 1869, when the water level of the lake rose to elevation 4,716 feet, the lake itself spilled into the river. Three small towns lie within the California portion of the basin: Davis Creek, Willow Ranch, and New Pine Creek. The Modoc Plateau covers an extensive area west of the valley, and the Devils Garden area of the plateau lies to the southwest.

In California, the eastern portion of the Goose Lake Valley ground water basin is subdivided into California portion of the Willow Ranch subbasin, the Davis Creek subbasin, and the Franklin Creek subbasin. Plates 4 and 5 show these subbasins.

The California portion of the Willow Ranch subbasin, about 11 miles long and 2 miles wide, extends south from the California-Oregon border to Willow Ranch. The easterly and southerly boundary of this subbasin is along the contact between the water-bearing materials, such as unconsolidated sediments and permeable volcanic rocks, and essentially nonwater-bearing rocks of the Warner Mountains, and those in the vicinity of Sugar Hill. The westerly boundary of this subbasin is considered to be the edge of the bed of Goose Lake because materials underlying the lake bed are relatively impermeable.

The Davis Creek subbasin generally comprises valley floor lands within a radius of about 3 miles from the community of Davis Creek. Only a portion of the boundary of the subbasin can be defined with available data. The northwesterly and northerly boundary of the subbasin is the edge of the bed of Goose Lake. The easterly boundary of the Davis Creek subbasin is along the contact between the water-bearing materials and essentially nonwater-bearing rocks of the Warner Mountains and the Sugar Hill complex. The southerly boundary is the surface water drainage divide between Roberts Creek and Linnville Creek. The extent of the subbasin to the west is unknown.

The Franklin Creek subbasin extends southerly from the Davis Creek subbasin and includes those lands drained by the North Fork Pit River. The easterly boundary is defined by the impermeable rocks of the Warner Mountains and the northerly boundary by the drainage divide between Roberts and Linnvil Creeks. Ground water data are lacking to define the westerly and southerly boundaries, therefore the surface water drainage boundary of Goose Lake Valle drainage basin is considered to be the boundary along the southerly and westerly perimeter of the subbasin.

Surface exposures of the various geologic formations of the California portion of Goose Lake Valley area are shown on Plate 3, Areal Geology, Goose Lake Valley Ground Water Basin. Plate 4, Generalized Lines of Equal Elevation of Water in Wells in Near-Surface Aquifers, Goose Lake Valley Ground Water Basin, Spring 1960, presents a generalized picture of the elevation of unconfined and semi-confined ground water within the California portion of the ground water basin. Plate 5, Generalized Lines of Equal Elevation of Water in Wells in Confined Aquifers, Goose Lake Valley Ground Water Basin, Spring 1960, indicates the general elevation to which confined ground water would rise in a well. Plate 6, Potential for Development of

Ground Water, Goose Lake Valley Ground Water Basin, presents preliminary evaluations of the potential for ground water development within the California portion of this basin. Areas of hazard because of poor quality water are also indicated on Plate 6.

Geologic History

During the Pliocene epoch, a large fresh water lake covered what is now north central Modoc County. The lake was bounded on the east by a range of hills that were in the process of being tilted to form the Warner Mountains. The lake apparently drained northwesterly toward the ancient Klamath River system. At some time in the early Pleistocene epoch, vents and fissures opened up west of the Warner Mountains and huge volumes of lava poured out. These lavas blocked the drainage to the Klamath River and the lake became isolated. Subsequently, drainage began to develop to the southwest as erosion of the canyon of North Fork Pit River began. As the canyon was deepened, the headwaters of the river moved northward. Finally, a new outlet to Goose Lake Valley was formed, and the lake drained southward into the Pit River system. After the close of the Pleistocene epoch, the climate became drier and the lake began to dry up. Today, Goose Lake is an intermittent lake, and it has been completely dry several times in the last 60 years.

Water-Bearing Formations

Table 9 briefly describes the geologic formations in Goose Lake Valley. Of these, the principal water-bearing formations in the California portion of the valley are Pliocene to Pleistocene lava flows, near-shore deposits, and Recent valley sediments.

GEOLOGIC FORMATIONS IN GOOSE LAKE VALLEY

Geologic Age			Geologic Formation	Stratigraphy	Approximate Thickness in Feet	Physical Characteristics	Water-Bearing Characteristics
Cenozoic	Quaternary	Recent	Sand dunes	Qsd	0-6	Qsd: Unconsolidated fine sand, wind deposited.	Contains little water.
Cenozoic	Quaternary	Recent	Lake deposits	Ql	0-1000	Ql: Unconsolidated clay and silty clay, alkali present.	May yield small amounts of poor quality water.
Cenozoic	Quaternary	Recent	Basin deposits	Qb	0-100	Qb: Unconsolidated, interstratified clay, silt, and sand. May have alkali.	Permeability moderate to slight. Yields small supplies of water to shallow wells.
Cenozoic	Quaternary	Recent	Intermediate alluvium	Qal	0-100	Qal: Unconsolidated, poorly sorted silt and sand with lenses of gravel.	Moderate permeability. Yields moderate quantities of water to wells.
Cenozoic	Quaternary	Recent	Alluvial fans	Qf	0-300	Qf: Unconsolidated to poorly consolidated, poorly stratified sands, gravels, and silts with lenses of clay.	East side fans are moderately to highly permeable and may yield moderate to large amounts of ground water to wells. West side fans are of relatively low permeability and may yield only small amounts of ground water to wells.
Cenozoic	Quaternary	Pleistocene	Terraces	Qt	0-50	Qt: Unconsolidated, poorly sorted gravels and sands with interstitial clay.	Moderate permeability. Yields moderate quantities of water to shallow wells.
Cenozoic	Quaternary	Pleistocene	Near-shore deposits	Qps	0-250	Qps: Slightly consolidated and cemented, poorly to well stratified pebbles and cobbles with lenses of sand and silt.	Moderate to high permeability. May yield large quantities of water to wells. Contains some confined water.
Cenozoic	Quaternary	Pleistocene	Pleistocene basalt	Qpvb	50-200	Qpvb: Highly jointed, flat-lying olivine basalt flows with interbedded scoriaceous zones.	Unit as a whole is highly permeable. Acts as a forebay to water-bearing sediments in Goose Lake Valley. May yield large quantities of water to wells.
Cenozoic	Tertiary	Pliocene to Pleistocene	Alturas formation	TQo	500	TQa: Slightly consolidated, well bedded tuffaceous sandstone.	Moderate permeability. May provide moderate quantities of water to deep wells, may contain confined water.
Cenozoic	Tertiary	Pliocene to Pleistocene	Plio-Pleistocene basalt	TQvb	500	TQvb: Highly jointed lava flows of basalt with zones of scoria and sediments.	Highly permeable on the whole. Acts as forebay to water-bearing sediments in Goose Lake basin. May yield large quantities of water to wells.
Cenozoic	Tertiary	Miocene to Pliocene	Rhyolite	Tvr	?	Tvr: Light-colored rhyolite, with zones of obsidian.	Essentially impermeable.
Cenozoic	Tertiary	Miocene	Basalt	Tmvb	?	Tmvb, Tmva, Tmv: Jointed lava flows of basalt and andesite, intrusive plugs of andesite, beds of tuff and tuff-breccia.	Nearly impermeable. May yield small amounts of water from fractures.
Cenozoic	Tertiary	Miocene	Andesite	Tmva			
Cenozoic	Tertiary	Miocene	Basalt, andesite, and tuff	Tmv			
Cenozoic	Tertiary	Miocene	Cedarville series	Tmc	7500	Tmc: Massive tuff-breccia, basalt and andesite.	Nearly impermeable. May yield small amounts of water from fractures and joints.

Pliocene to Pleistocene Lava Flows. The Pliocene to Pleistocene lava flows are generally highly permeable and where exposed at the ground surface are excellent areas for ground water recharge. Only a few producing water wells have been drilled into the basalts; consequently, only limited data on the water yielding capabilities of the basalt are available.

Lava flows on the west side of Goose Lake appear to contain numerous permeable zones which may be capable of providing large quantities of ground water to irrigation wells. In addition, well log data indicate the presence of several basalt flows buried within the valley sediments in the Davis Creek subbasin. These layers of fractured lava are interbedded with sand and clay and yield moderate to high quantities of ground water to wells.

Near-Shore Deposits. Extensive near-shore deposits occur along the east side of Goose Lake Valley. The near-shore deposits appear to be moderately to highly permeable, especially in a horizontal direction. Occasional cemented zones and beds of silt and clay tend to confine ground water, and the more permeable beds of sand and gravel yield artesian water to wells. The near-shore deposits may yield large quantities of ground water to wells.

Recent Valley Sediments. Recent valley sediments include alluvial fans, intermediate alluvium, and basin deposits. The lake deposits in Goose Lake Valley are also included with the Recent valley sediments. As lake deposits yield only small amounts of ground water to wells they will not be discussed below.

Alluvial fans are generally the most permeable of the valley sediments. The east side alluvial fans, about 300 feet thick, are considered to be the most important sources of ground water. The upper portions of the

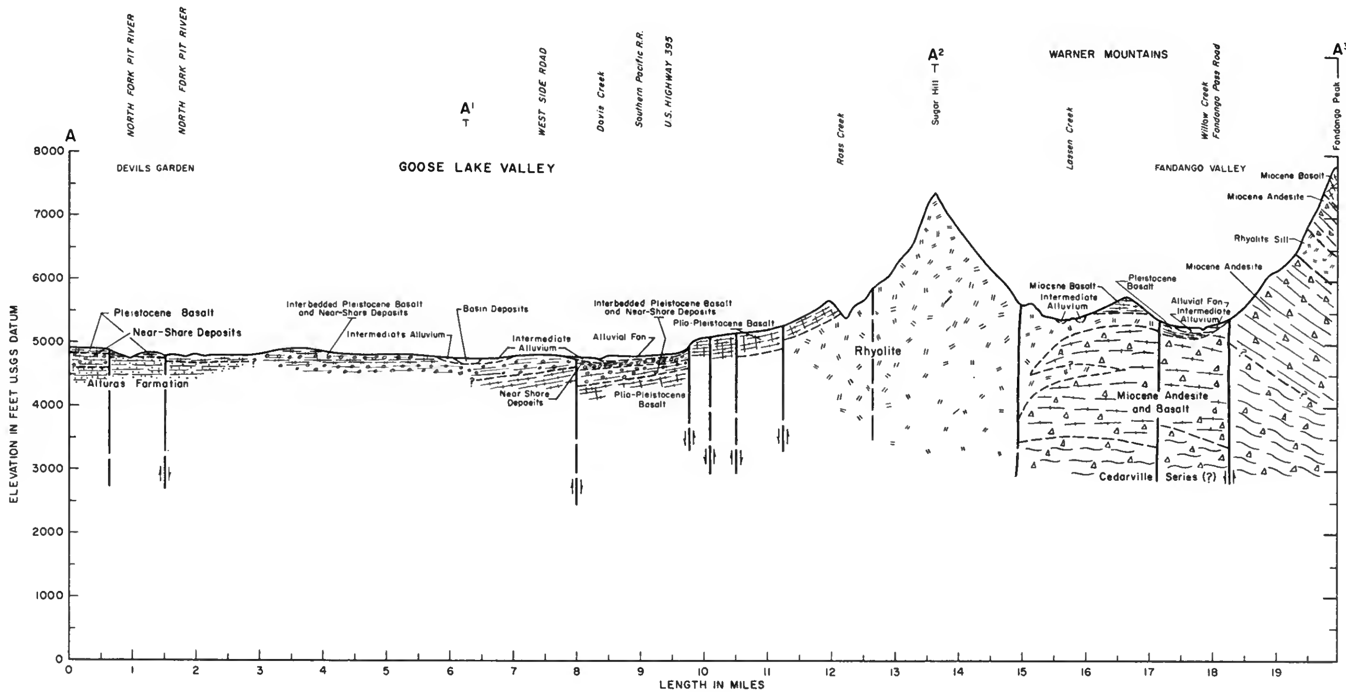
fans are moderately to highly permeable and if sufficiently recharged can yield large quantities of ground water to wells. The middle and lower portions of the fans, although less permeable, contain confined aquifers which may yield moderate amounts of ground water to wells. In contrast, alluvial fans along the west side of the valley are only about 100 feet thick and are of relatively low permeability; hence, they can yield water sufficient only for domestic and stock purposes.

Intermediate alluvium occurs at the lower limits of many alluvial fans. It is generally about 100 feet thick and is underlain in some areas by less permeable lake deposits and in other areas by more permeable alluvial fans and near-shore deposits. The intermediate alluvium is moderately permeable and if sufficiently recharged and of sufficient thickness is capable of yielding moderate quantities of water to shallow domestic and stock wells.

Basin deposits occur on the flat, poorly drained portions of the valley. They may be up to 100 feet thick and are underlain by relatively impermeable lake deposits, or in a few localities, by more permeable alluvial fan or near-shore deposits. Numerous areas of basin deposits are crusted with alkali. Because of their low to moderate permeability, the basin deposits yield only small quantities of ground water to wells.

Influence of Geologic Structure on Ground Water

Goose Lake Valley is a downfaulted block bounded by many scarps. Generalized geologic structure of the valley is presented on Figures 9 and 10, which are geologic sections showing the probable structural condition to a depth of about 1,500 feet below the lake.



See Plate 3 for location of section.

Figure 9. GENERALIZED GEOLOGIC SECTION A-A¹-A²-A³
GOOSE LAKE VALLEY GROUND WATER BASIN

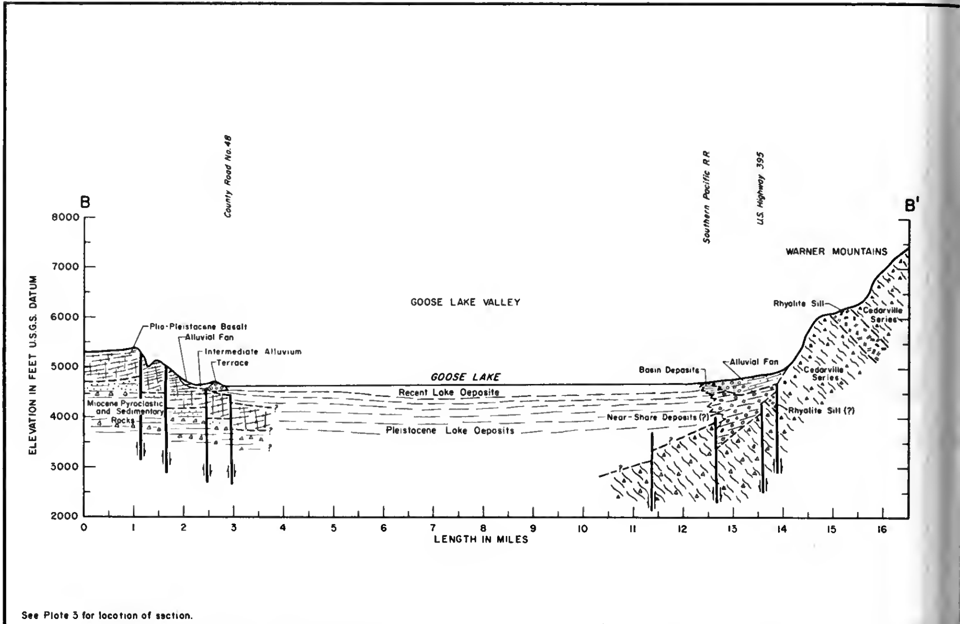


Figure 10. GENERALIZED GEOLOGIC SECTION B-B'
GOOSE LAKE VALLEY GROUND WATER BASIN

As may be noted from Plate 3 and Figures 9 and 10 there are numerous faults on the west side of the valley. These faults probably do little to impede the movement of ground water through the permeable basalt. In fact, precipitation falling on the surface of the basalt seeps downward to the water table along many of these faults. Many of the faults on the east side of the valley are filled with impermeable gouge and are completely within impermeable rock and hence have a negligible effect on ground water recharge. Some of the sediments beneath the valley floor may have faults cutting through them. These faults may create ground water barriers by forming impermeable gouge or by positioning permeable strata opposite impermeable strata.

The geologic sections indicate that there may be sediments of unknown extent underlying the basalt flows. These sediments may serve as permeable zones through which ground water may move either into or out of the valley.

Recharge and Movement of Ground Water

Upland recharge areas, shown on Plates 4 and 5, consist of permeable basalt flows of Pliocene to Pleistocene age. Precipitation and surface runoff infiltrates the permeable materials and then percolates valleyward to recharge the valley sediments. The portion of the surface drainage area boundary on the west side of Goose Lake Valley shown on Plate 4 approximates the extent of the recharge area on the west side of Goose Lake Valley ground water basin.

Mean seasonal precipitation along the shore of the California portion of Goose Lake is approximately 12 to 14 inches. Mean seasonal precipitation ranges to about 18 inches along the foothills of the Warner Mountains and to about 16 inches at the southern edge of the valley floor. The precipitation station within Goose Lake Valley possessing the longest record is Lakeview, Oregon, where the estimated mean seasonal precipitation is 13.30 inches. The recorded maximum and minimum precipitation at this station is 22.82 inches during the 1906-07 season, and 6.91 inches during the 1930-31 season, respectively. This degree of variation of precipitation is probably typical for Goose Lake Valley.

Most of the ground water recharge to deeper aquifers along the east side of the California portion of Goose Lake Valley is derived from infiltration of surface water, generally along the foothill portions of stream channels. The streamflow here is generated by precipitation on the

Warner Mountains, mostly occurring in the form of snow during the winter months. The mean seasonal precipitation on these mountains is approximately 18 inches along the foothills and reaches estimated maximums of 32 inches near Mount Vida and 34 inches along the crest approximately 3 miles east of Scammon Reservoir. A relatively large portion of precipitation occurring along the west side of the valley infiltrates upland recharge areas. On the Devils Garden, mean seasonal precipitation is about 12 to 14 inches. Even though these precipitation values are relatively low, a generally thin soil mantle and limited amounts of natural vegetation in the Devils Garden area allows a considerable portion of this precipitation to recharge underlying ground water bodies. North of the Devils Garden, where soils are deeper and vegetation is of greater density, precipitation is also greater. Within this portion of the west side recharge area, mean seasonal precipitation ranges from 14 inches near Poindexter Reservoir to upwards of 24 inches along mountain peaks near the boundary between California and Oregon.

On the west side of the valley between McGinty Point and the State boundary, ground water intercepted by wells is moving from the Modoc Plateau eastward toward Goose Lake. No information is presently available to determine the direction of movement south of McGinty Point, although the most probable direction of movement within the first 300 feet of depth is toward Goose Lake in Township 45 North, Range 13 East, M.D.B.&M., and toward North Fork Pit River and its tributary streams in Township 44 North, Range 13 East, M.D.B.&M.

Generalized lines of equal elevation of water in wells are shown on Plates 4 and 5. The general direction of ground water movement indicated for most ground water within the California portion of the east side of Goose Lake Valley is from the foothills of the Warner Mountains toward Goose Lake,

while the remaining portion moves toward North Fork Pit River and its tributary streams. Ground water movement within each of the three subbasins of the valley is discussed below.

Willow Ranch Subbasin. There are two ground water bodies within Willow Ranch subbasin. The upper, essentially unconfined body, is intercepted by wells of depths usually less than 50 feet. Recharge to this ground water body is from streams draining the Warner Mountains. Water from these streams infiltrates the highly permeable upper portions of alluvial fans and then moves westward toward Goose Lake. Return water from irrigation within this subbasin is evidently also a source of recharge to this upper ground water body.

The lower ground water body is confined and probably occurs in near-shore and related deposits. The piezometric surface of this body has a pattern similar to that of the overlying, essentially unconfined, ground water body. The piezometric surface of the lower body ranges from 30 feet below the ground water table of the upper body along portions of the foothills, to perhaps 20 feet above the water table at some places at the edge of the lake bed. This lower confined ground water body is recharged from deep percolation of ground water in the upper portions of alluvial fans. The area depicted in blue on Plate 5 is where the piezometric surface of this lower ground water body is above the ground surface.

Davis Creek Subbasin. Plates 4 and 5 indicate the probable location of the ground water divide between the Davis Creek and Franklin Creek subbasins in the Spring of 1960. As a ground water divide is subject to change in location, the surface water drainage divide located north of the ground water divide is considered as the boundary between the two subbasins.

The analysis of the elevation of the ground water surface determined at certain wells within Davis Creek subbasin indicates the existence of at least three separate ground water movement patterns. Each pattern is assumed to represent a separate ground water body. Wells of depths generally less than 50 feet intercept ground water moving within near-surface materials in a predominately westerly to northwesterly direction toward Goose Lake. The recharge to this ground water body is from alluvial fans along foothill slopes of the Warner Mountains and from channels of valley floor streams. The ground water mound in the vicinity of Lakeshore Ranch shows that overlying irrigated lands also recharge this ground water body. Local areas of aquifer confinement, one of which is located in Section 19, Township 45 North, Range 14 East, M.D.B.&M., exist within this essentially unconfined ground water body. The observed confinement apparently results from cementation of the upper portions of gravel bed aquifers within certain areas of the near-shore deposits.

Wells of depths between 100 and 400 feet apparently intercept ground water moving within near-shore deposits and interbedded Pleistocene basalts. Ground water in this body is recharged by deep percolation in the upper portions of alluvial fans of Davis Creek and Roberts Creek and moves in a northwesterly direction toward Goose Lake.

Certain wells of depths in excess of 400 feet located in or close to Section 18, Township 45 North, Range 14 East, M.D.B.&M., apparently intercept a third major ground water body which is confined in sediments and Plio-Pleistocene basalts underlying the Pleistocene basalts. There is some evidence that shallower wells 2 to 3 miles north of the community of Davis Creek also intercept this ground water body. Evidence from a few wells which have intercepted this ground water body indicate that the direction of movement is southwesterly from its apparent recharge area within the

Plio-Pleistocene basalt east and northeast of the community of Davis Creek. This apparent direction of movement of the defined portion of this ground water body is therefore perpendicular to the direction of movement of the two overlying ground water bodies.

Franklin Creek Subbasin. Geologic evidence indicates that several ground water bodies may exist within the Franklin Creek subbasin, particularly in the area near Devils Garden. Wells within this subbasin confirm the existence of at least two ground water bodies. However, as ground water elevation information is available principally from shallow wells, only generalized lines of equal elevation of water in wells in near-surface aquifers can be determined at this time. The general direction of movement of this ground water body is from recharge areas within alluvial fans along the foothills of the Warner Mountains, westerly to southwesterly toward North Fork Pit River and certain tributary streams. Overlying irrigated lands within this subbasin undoubtedly contribute to the recharge of this ground water body. There is some evidence that a portion of this ground water body is intercepted by an unnamed slough parallel to the Southern Pacific Railroad, while a remaining portion of this ground water body continues to move westerly, probably to be intercepted by the "outlet channel" of Goose Lake.

Present information indicates that the near-surface ground water body is essentially unconfined east of the slough which parallels the Southern Pacific Railroad. No evidence is available pertaining to confinement conditions west of this slough. The faulted basalt in Sections 13 and 24, Township 44 North, Range 13 East, appears to act as a restriction to the southerly movement of this ground water body toward North Fork Pit River. This restriction apparently accounts for numerous springs on Crowder Ranch located about 6 miles southerly of the community of Davis Creek.

Present Use of Ground Water

Approximately 115 square miles of the 190 square miles of valley floor lands within the California portion of Goose Lake Valley are occupied by the bed of Goose Lake. Of the remaining 75 square miles, or 48,000 acres, 37,000 acres are considered suitable for the production of irrigated crops. Approximately 9,000 acres of these lands are presently irrigated, primarily by waters diverted from unregulated streams.

The majority of the 119 wells located during 1957 were utilized primarily for domestic and stock watering purposes. Only 9 wells were irrigation wells. These wells, the yields of which range from 525 to more than 2,000 gallons per minute, provide total or supplemental irrigation water to approximately 1,000 acres of cultivated lands. Based on the apparent availability of ground water storage and rechargability of the permeable materials of the basin, present pumpage of ground water apparently extracts only a very minor portion of the total amount of ground water available for development.

Ground Water Development Potential

Within the valley floor area of Goose Lake Valley all four zones of potential for development of ground water are present. The area of the valley floor in each classification is shown on Plate 6. The general conditions which presently govern the potential for development of ground water within each zone found in this basin are discussed below.

"A" Zone. The "A" Zone areas are underlain by permeable materials that receive adequate recharge. The areas are situated on the middle and upper portions of the alluvial fans of certain creeks draining the Warner Mountains. The extent of the area of the "A" Zone of the Davis Creek fan is

modified by several buried lava flows. These buried lava flows and their associated sediments apparently contain large quantities of confined ground water.

"B" Zone. Much of the irrigable land in Goose Lake Valley is located within "B" Zone areas. On the east side of the valley, most of the "B" Zone areas are underlain by alluvial fan materials. These materials are similar to those underlying adjacent "A" Zone areas, although in general they are somewhat thinner and less permeable. The recharge potential for the "B" Zone areas on the east side is generally somewhat less than for the "A" Zone areas.

The Davis Creek "B" Zone area is probably underlain to some extent by the same buried, permeable basalt flows which underlie the Davis Creek "A" Zone area. The presence of less permeable near-shore deposits in this "B" Zone probably reduces the overall permeability and hence reduces the potential yield of ground water to wells. The intermediate alluvium along lower portions of Willow and Lassen Creeks are underlain by less permeable near-shore deposits. The intermediate alluvium appears to be fairly permeable and could provide satisfactory yields of ground water to wells. Along the west side of Goose Lake, the "B" Zone areas are composed of intermediate alluvium and terraces underlain by basalt flows containing highly permeable layers of fragmented volcanic rock. Wells here could produce large quantities of ground water provided a sufficient number of these layers are intercepted. Recharge to these layers appear to be in sufficient quantity to supply ground water for irrigation requirements within the "B" Zone areas along the west side of Goose Lake Valley.

"C" Zone. The "C" Zone areas are situated in four general locations. One area extends from New Pine Creek south to Sugar Hill and is underlain entirely by intermediate alluvium, basin deposits, and near-shore deposits. The second "C" Zone area is west and northwest of the community of Davis Creek. This zone contains intermediate alluvium, basin deposits, and near-shore deposits near the surface, while below a depth of about 50 feet, less permeable lake and near-shore deposits are found. Where lake deposits underlie the surface materials, there is the possibility that ground water could be obtained only from the surficial deposits. The third "C" Zone area is situated north and southeast of Davis Creek and is composed entirely of intermediate alluvium, alluvial fan, and near-shore deposits. Because these three areas have no appreciable surface recharge, extracted ground water could only be replenished by lateral movement from areas of recharge located along flowing streams. The ground water development potential of these three "C" Zone areas is thus reduced. The fourth "C" Zone area is west and south of Goose Lake. Although similar to adjacent "B" Zone areas, it also probably has less surface recharge and consequently is considered to have a lower overall development potential.

"D" Zone. The areas classified as "D" Zone have the lowest ground water development potential and are of two basic types. One type is located adjacent to Goose Lake and is composed of basin deposits underlain at depths of less than 50 feet by relatively impermeable lake deposits. Any water in wells located here would be derived mainly from shallow materials, in many places by slow seepage from the lake itself. The other type is located in areas adjacent to outcrops of impermeable rock. Surface materials in these areas may be permeable, but because they are underlain at shallow depths by impermeable rock, wells in these locations would yield little, if any, ground water.

General. With the present level of agricultural development, the irrigation water supply derived from direct diversion of surface water is usually sufficient for most lands until about the middle of June when there is usually a need for supplemental irrigation water. As agricultural development increases the need for supplemental water will increase correspondingly. Ground water in many instances can be utilized to meet the increased need.

Within Willow Ranch subbasin, irrigable lands underlain by alluvial fans appear suitable for an increased level of ground water development. At some increased level of development it appears that natural recharge will be insufficient for the required pumpage. In this event, the construction of ground water recharge facilities may forestall overdraft conditions. Increased ground water development probably will aggravate the present undesirable water quality condition within particular portions of this subbasin. It may be possible to control this problem to some extent by development of selected aquifers containing good quality ground water. Proper sealing of wells which act as conduits between aquifers containing the poorer quality waters and aquifers containing the better quality waters should aid in maintaining the quality of ground water. Within a portion of this subbasin, the piezometric surface is above the ground surface. The flowing wells within this area are particularly useful for stockwatering. Caution should be exercised in construction of such wells within particular areas as it appears possible that the ground water developed may be of poor quality.

Within the Davis Creek and Franklin Creek subbasins the level of ground water development which may be achieved before natural recharge facilities become a limiting factor, appears to be higher than within the Willow Ranch subbasin. It appears possible that the Alturas formation

underlies most of Franklin Creek subbasin and may extend under a considerable portion of Davis Creek subbasin. If so, wells in the order of 800 feet deep may intercept ground water within this formation which apparently is adequatel recharged. Also, buried basalt flows may be intercepted at depth.

Ground Water Storage Capacity

The ground water storage capacity to a depth of 500 feet has been estimated to be approximately 1,000,000 acre-feet. How much of this quantity is usable, or how much usable storage exists below 500 feet is not presently known. It is reasonable to assume that a significant amount of ground water could be developed.

Quality of Ground Water

Ground water in Goose Lake Valley ground water basin is generally of excellent mineral quality, being usually calcium bicarbonate in character and suitable for most beneficial uses. There is an area of approximately 3 square miles located east of Goose Lake and south of New Pine Creek where wells deeper than 200 feet have encountered sodium bicarbonate waters. These waters contain excessive concentrations of fluoride and boron and are generall considered unsuitable for irrigation or domestic uses. The waters are thermal and are found associated with and in close proximity to several fault zones which traverse the area.

Water Quality Problems

The most significant body of poor quality water presently existing in Goose Lake Valley ground water basin is the thermal water shown on Plate 6. However, Goose Lake, which overlies a large portion of the ground water basin, is also poor in quality, because it contains high concentrations of total dissolved solids, sodium, and boron.

Under present development and existing hydrologic conditions, these poor quality waters do not pose a significant threat to adjacent good quality waters. Increasing ground water extractions could depress ground water levels near the lake, and new ground water gradients could easily be established that would lead to the migration of poor quality waters and subsequent impairment of adjacent good quality waters.

In the area underlain by thermal mineralized water, any improperly constructed or unused wells over 200 feet deep could create a direct interconnection with the deep mineralized waters and shallow good quality waters, and result in the impairment of the good quality waters.

Conclusion

Additional ground water may be developed within Goose Lake basin. This is particularly true for areas underlain by alluvial fans along the east side of the California portion of the valley floor. Within the northern portion of this side of the valley floor, there appears to be a ground water quality problem area. Caution should be exercised in development of ground water within this area.

If the Alturas formation and buried basalt flows underlie the southern portion of the valley floor, and if these materials are recharged from the Devils Garden area, ground water development potential of the southern portion of the valley floor is considerably enhanced.

It is concluded that the basic data collection activities of the Department of Water Resources should be continued in order to facilitate future quantitative and qualitative analysis of the ground water basin. Encouragement should be offered to local agencies in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

Alturas Ground Water Basin

Alturas ground water basin is located in central Modoc County and includes areas adjacent to Pit River and its tributaries near the City of Alturas. The valley floor elevation is about 4,300 feet. South Fork Pit River heads in Jess Valley in the south Warner Mountains and flows in a westerly direction through the small town of Likely. From Likely the river turns north and flows through South Fork Pit River Valley to Alturas where it joins North Fork Pit River. North Fork Pit River flows in a southerly direction from near Goose Lake to its confluence with South Fork Pit River at Alturas. From this confluence, Pit River flows in a westerly direction through Warm Springs Valley. Alturas ground water basin is bounded by the Warner Mountains on the east, Devils Garden on the north, and rolling hills to the south and west.

Alturas ground water basin is composed of South Fork Pit River Valley subbasin and Warm Springs Valley subbasin. As shown on Plate 8, South Fork Pit River Valley subbasin consists of lands adjacent to both North Fork Pit River and South Fork Pit River. It also includes some lands located westerly of the confluence of the two forks of the Pit River. The remaining area of Alturas ground water basin is designated as Warm Springs Valley subbasin.

Surface exposures of the various geologic formations of the Alturas area are shown on Plate 7, Areal Geology, Alturas Ground Water Basin. Plate 8, Generalized Lines of Equal Elevation of Water in Wells in Aquifers, Alturas Ground Water Basin, Spring 1960, is a generalized picture of the elevation of the ground water within the ground water basin. Plate 9, Potential for Development of Ground Water, Alturas Ground Water Basin,

presents the preliminary evaluations of the potential for ground water development within this basin. Areas of hazard because of poor quality water are also indicated on Plate 9.

Geologic History

During the late Miocene epoch, when the Warner Mountains were being tilted upward, the Alturas basin was the site of a broad valley occupied by a very large lake. The valley received sediments from the mountains, which sediments now compose a portion of the lower member of the Alturas formation. During the Pliocene and early Pleistocene epochs, Tule Mountain, an ancient volcano, produced many lava flows which poured out into the valley. During the same time interval, violent explosions shook the land, and huge volumes of billowing ash and sulfurous gas filled the air. There were also associated eruptions of clouds of volcanic solids and gasses which raced downhill at high speeds. After blanketing much of the valley, the volcanic clouds solidified to form the Warm Springs tuff. Again a period of quiescence ensued, and a lake reoccupied the valley. Sediments from this second lake make up the upper member of the Alturas formation. Widespread fissure eruptions of lava during the Pleistocene epoch created Devils Garden. Contemporaneous and subsequent faulting, folding, and erosion formed the Alturas basin. Near the close of the Pleistocene epoch, there were lakes occupying South Fork Pit River Valley and Warm Springs Valley. The two lakes were connected by a strait along Rye Grass Swale. Eventually, erosion formed the present course of Pit River, and the two lakes were drained leaving the valleys much as they are today.

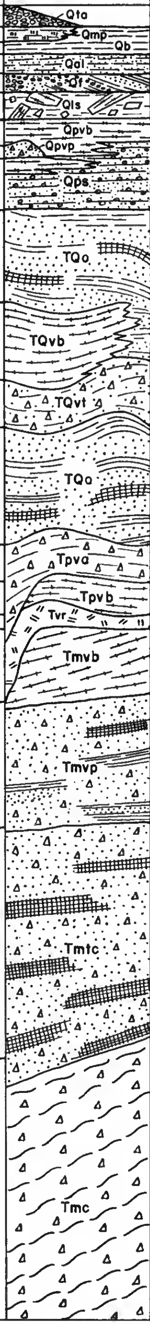
Water-Bearing Formations

Table 10 briefly describes the geologic formations in Alturas basin. Of these, the principal water-bearing formations are Plio-Pleistocene and

TABLE 10

GEOLOGIC FORMATIONS IN ALTURAS BASIN

Geologic Age				Geologic Formation	Stratigraphy	Approximate Thickness in Feet
Cenozoic	Quaternary	Recent		Talus	Qta	0-75
Cenozoic	Quaternary	Recent		Muck and Peat	Qmp	0-50
Cenozoic	Quaternary	Recent		Basin Deposits	Qb	0-50
Cenozoic	Quaternary	Recent		Intermediate Alluvium	Qal	0-75
Cenozoic	Quaternary	Recent		Alluvial Fans	Qf	0-75
Cenozoic	Quaternary	Recent		Landslide	Qls	50-100
Cenozoic	Quaternary	Pleistocene		Pleistocene Basalt	Qpvb	50-150
Cenozoic	Quaternary	Pleistocene		Pyroclastic Rocks	Qpvp	?
Cenozoic	Quaternary	Pleistocene		Near-Shore Deposits	Qps	0-200
Cenozoic	Quaternary	Plio-Pleistocene		Upper Member, Alturas Formation	TQo	400
Cenozoic	Quaternary / Tertiary	Plio-Pleistocene		Plio-Pleistocene Basalt Member	TQvb	50-250
Cenozoic	Tertiary	Plio-Pleistocene		Warm Springs Tuff Member	TQvt	100-400
Cenozoic	Tertiary	Plio-Pleistocene		Lower Member, Alturas Formation	TQo	400
Cenozoic	Tertiary	Pliocene		Andesite	Tpva	?
Cenozoic	Tertiary	Pliocene		Basalt	Tpvb	?
Cenozoic	Tertiary	Pliocene		Rhyolite	Tvr	?
Cenozoic	Tertiary	Miocene	Miocene Volcanic Rocks	Basalt	Tmvb	300
Cenozoic	Tertiary	Miocene	Miocene Volcanic Rocks	Pyroclastic Rocks	Tmvp	1000
Cenozoic	Tertiary	Miocene		Turner Creek Formation	Tmtc	4000
Cenozoic	Tertiary	Miocene		Cedarville Series	Tmc	7500



Physical Characteristics	Water-Bearing Characteristics
Qta: Unconsolidated blocks of rock. Of small areal extent.	Highly permeable, but usually above zone of saturation. Yields water to springs.
Qmp: Unconsolidated deposits of organic muck and fibrous peat. Found only in Jess Valley.	Very low permeability. Unimportant as source of ground water.
Qb: Unconsolidated, interstratified clay, silt, and fine sand.	Permeability moderate to slight. May yield small supplies of water to wells.
Qal: Unconsolidated, poorly sorted silt and sand with some lenses of gravel.	Moderately permeable. Yields moderate quantities of water to shallow wells.
Qf: Unconsolidated to poorly consolidated, rudely stratified sand, silt, and gravel, with lenses of clay.	High permeability. May yield large quantities of water to wells; may contain confined water.
Qls: Semiconsolidated mixture of blocks of basalt in matrix of clay and sand.	Of low permeability and of little importance to ground water.
Qpvb: Highly jointed, flat-lying olivine basalt flows with interbedded scoriaceous zones.	Unit as a whole moderately permeable. Acts as forebay for recharge to adjacent sediments.
Qpvp: Semiconsolidated red and black cinders.	Moderately permeable but contains little water due to being above saturated zone.
Qps: Slightly consolidated and cemented, poorly to well stratified pebble and cobble gravel with lenses of sand and silt.	Of moderate permeability. May yield fair to moderate quantities of water to wells.
TQa: Lake deposited tuff, ashy sandstone, gravel, and diatomite. Indistinguishable from lower member.	Moderate to high permeability. Yields large quantities of water to wells. Contains confined water.
TQvb: Jointed, nearly flat-lying flows of basalt with zones of scoria.	Unit as a whole is moderately permeable. Yields water to numerous springs. Acts as forebay for recharge to adjacent sediments. May yield moderate amounts of water to wells.
TQvt: Massive pumice lapilli tuff, jointed beds of welded tuff, minor beds of ashy sandstone.	Transmits small quantities of water along joints and fractures. Sandstone beds may yield moderate quantities of water.
TQa: Indistinguishable from upper member. May be Miocene in part.	Same as upper member.
Tpva: Plugs of massive and platy andesite.	Essentially impermeable.
Tpvb: Jointed, dipping flows of basalt.	Fair to poor overall permeability. Locally yields small amounts of water to springs.
Tvr: Massive, light-colored plugs of rhyolite.	Essentially impermeable.
Tmvb: Flows of jointed vesicular basalt.	Transmits only minor quantities of water along joints.
Tmvp: Bedded mudflows, tuffs, ashy sandstone, and diatomite. May be correlative to Turner Creek formation. Upper portion may grade into lower member of Alturas formation.	Of low overall permeability. A few permeable beds may yield limited quantities of ground water to wells.
Tmtc: Massive mudflows and tuffs with beds of ashy sandstone and diatomite. Upper portion may be correlative to lower member of Alturas formation.	Of low overall permeability. A few permeable beds may yield limited quantities of ground water to wells.
Tmc: Massive tuff breccia, basalt, and andesite.	Nearly impermeable. May yield small amounts of water from fractures and joints.

Pleistocene lava flows, the Alturas formation, near-shore deposits, and Recent valley sediments.

Plio-Pleistocene and Pleistocene Lava Flows. Plio-Pleistocene and Pleistocene lava flows found in Alturas basin are generally moderately permeable and consequently where exposed comprise a ground water recharge area. There are no known water wells drilled in areas of surface exposures of these lava flows. Therefore, no direct data on the water yielding capabilities of the basalt are available. The numerous springs in basalt areas, however, attest to the water yielding potential of certain zones. Several wells south of Alturas intercept buried lava flows. Although it is not possible to ascertain the exact quantity of ground water obtained from each lava flow, it is probable that the lava flows yield more ground water than the surrounding materials of the Alturas formation.

Alturas Formation. The Alturas formation is widespread both at the surface and at depth in Alturas ground water basin. The formation consist of moderately consolidated, flat-lying beds of tuff, ashy sandstone, and diatomite. All of the materials were deposited in lakes which occupied this area at various times from the latter part of the Miocene epoch to the Pleistocene epoch. The sedimentary portion of the Alturas formation consists of two nearly identical members separated by a Plio-Pleistocene basalt member and the Warm Springs tuff member. The two sedimentary members are not differentiated on Plate 7 because of the marked similarity of the sedimentary beds making up the upper and lower members.

The sediments of the Alturas formation are the principal water yielding materials in Alturas ground water basin. The sediments have a moderate to high overall permeability, and where saturated, may yield ground

water in quantities sufficient for irrigation purposes. They contain both unconfined and confined ground water.

Near-Shore Deposits. Extensive near-shore deposits occur on the east side of North Fork Pit River Valley. Minor areas of these deposits also occur at other localities within Alturas ground water basin. There is only one well in Alturas basin known to draw its entire supply from the near-shore deposits. Based on this well, it appears that the near-shore deposits are moderately permeable and, where saturated, may yield fair to moderate supplies of unconfined and semiconfined ground water to wells.

Recent Valley Sediments. This group includes alluvial fans, intermediate alluvium, and basin deposits. All of the Recent valley sediments are fairly thin, being at most 50 feet in thickness. Of the three, the alluvial fans are usually the most permeable as they are frequently composed of highly permeable mixtures of silt, sand, and gravel. Where they are within the zone of saturation, the fans will usually provide high yields of confined and semiconfined water to wells. The intermediate alluvium is of somewhat lower permeability as it contains a greater amount of silt and clay. Intermediate alluvium, however, can provide moderate quantities of ground water to wells. The basin deposits are the least permeable of the Recent valley sediments. These deposits contain large percentages of silt and clay and thus yield only small quantities of water to wells.

Influence of Geologic Structure on Ground Water

The geologic structure of the Alturas area is one of gentle anticlines and synclines broken by numerous faults. An indication of this structure is shown in Figures 11 and 12, which are generalized geologic sections showing the probable structural conditions to depths of about 1,000 feet.

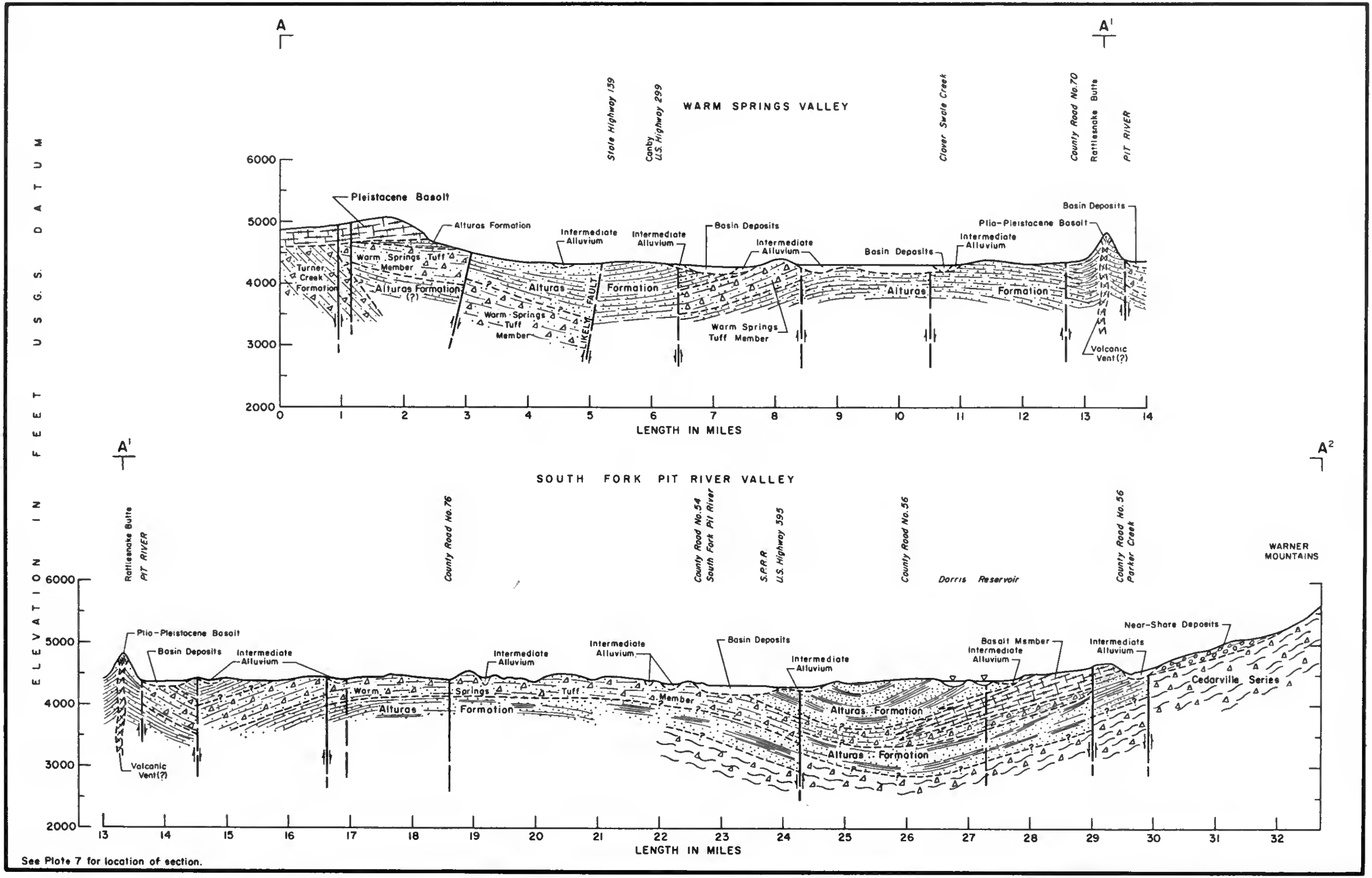


Figure 11. GENERALIZED GEOLOGIC SECTION A–A'–A²
ALTURAS GROUND WATER BASIN

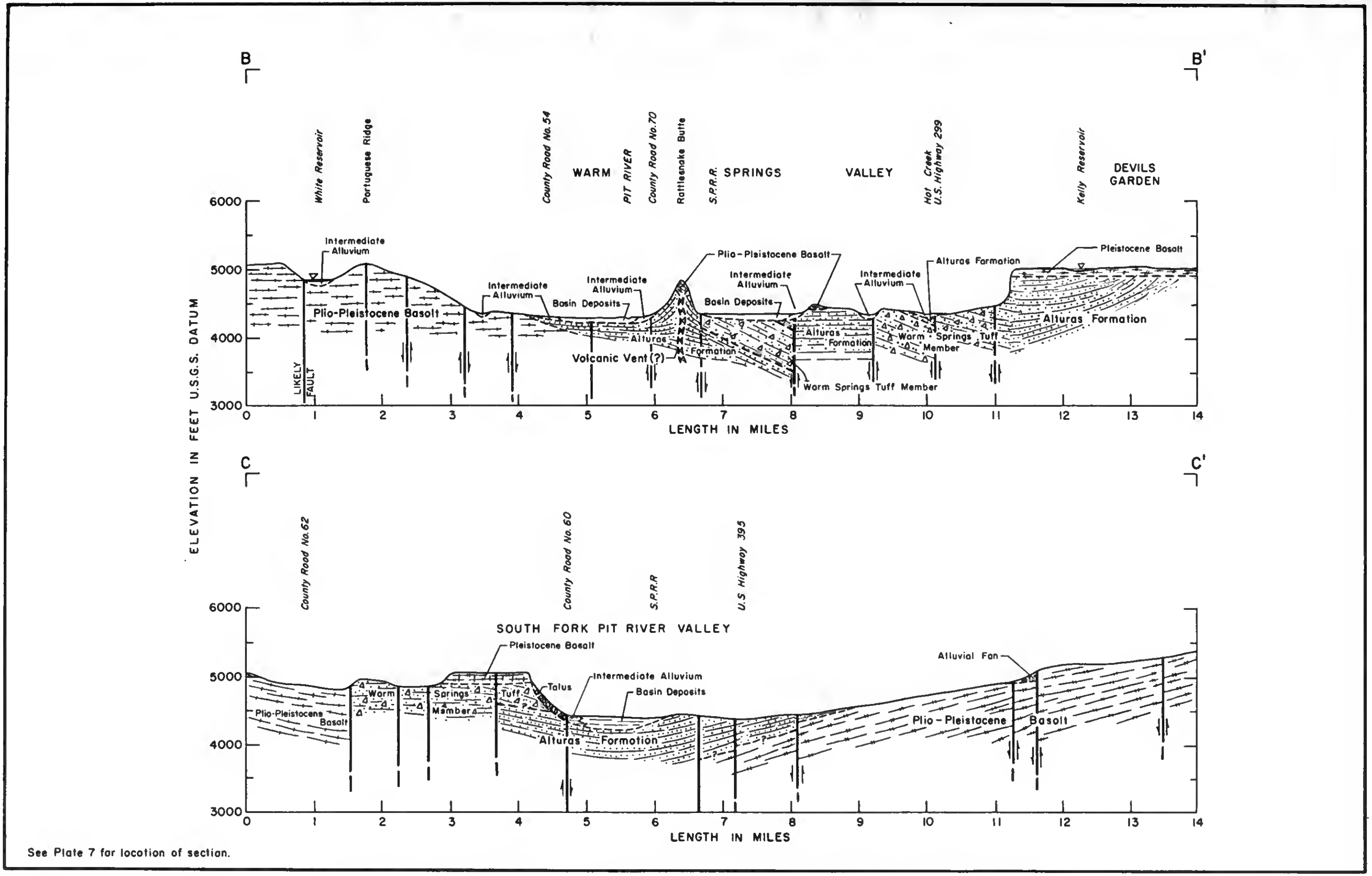


Figure 12. GENERALIZED GEOLOGIC SECTIONS B-B' AND C-C'
ALTURAS GROUND WATER BASIN

The Alturas formation has been folded into three gentle faulted synclines. The axis of one passes in a northwesterly direction through the City of Alturas; the second is roughly parallel to the first and passes just east of Rattlesnake Butte; the third is also generally parallel and passes just west of the town of Canby. The three synclines are separated by gentle anticlines. Synclines are important to ground water in that water confined within a given bed will generally be under a greater head along the axis of the syncline than along its limbs. Anticlines are important to ground water in that they may position certain water-bearing beds closer to the ground surface.

Many of the faults shown on Plate 7 may have distinct effects upon ground water. The faults cutting through the Pliocene to Pleistocene lava flows frequently contain permeable zones which enable precipitation to infiltrate and then percolate laterally and downward. This accounts for the springs located along many fault zones. If the permeable zones along a fault extend deep enough into the earth, ground water can circulate to great depths and return to the surface as heated, mineralized water such as is found at Kelly Hot Springs.

In contrast, faults cutting through sedimentary materials may position an aquifer opposite an aquiclude and thus restrict or impede the movement of ground water. This is the case wherever permeable beds of the Alturas formation have been moved opposite impermeable beds. A barrier to ground water movement may also exist where a gouge-filled fault zone cuts across permeable beds.

Recharge and Movement of Ground Water

Upland recharge areas, shown on Plate 8, consist of permeable lava flows of Plio-Pleistocene and Pleistocene age. Precipitation falling

upon these areas infiltrates the lava flows, and moves toward the valley floor area.

The mean seasonal precipitation on the valley floor areas within Alturas basin is approximately 12 inches in Warm Springs Valley, ranges from approximately 6 to 12 inches in South Fork Pit River Valley, and averages about 12 inches in North Fork Pit River Valley. The mean seasonal precipitation on the upland recharge areas to the north and southwest of the valley floor areas ranges from 12 to upwards of 16 inches. On the upland recharge area to the east of the floor of North Fork and South Fork Pit River Valleys, the mean seasonal precipitation ranges from 8 to 16 inches. The recorded maximum and minimum seasonal precipitation at the Alturas Ranger Station, located near the southern edge of the City of Alturas, was 21.09 inches during the 1951-52 season and 6.44 inches during the 1930-31 season. The mean seasonal precipitation for the Alturas Ranger Station is 12.16 inches per year. Variations from mean seasonal precipitation similar to those at the Alturas Ranger Station are to be expected over the valley floor and upland recharge areas of the Alturas ground water basin.

The direction of movement of ground water generally follows the topography in most places, as indicated by the generalized lines of equal elevation of water in wells shown on Plate 8. The various faults which cross the basin undoubtedly modify this general movement pattern.

Alturas ground water basin is divided into two subbasins: South Fork Pit River subbasin, and Warm Springs Valley subbasin. This division is based on the presence of a material of low permeability running the length of the mesa land which separates South Fork Pit River Valley subbasin from Warm Springs Valley subbasin. Ground water movement within each of these subbasins is discussed below.

South Fork Pit River Valley Subbasin. Along the northwesterly side of North Fork Pit River Valley, ground water apparently moves through the Alturas formation and Warm Springs tuff toward the valley floor area. Along the southeasterly side of this valley, the probable direction of movement of some of the ground water is westerly toward North Fork Pit River. The remainder moves southwesterly toward Parker Creek where it is partially intercepted. The basalt and Warm Springs tuff near Highway 395 bridge across North Fork Pit River, Section 33, Township 43 North, Range 13 East, M.D.B.&M., acts as a partial restriction to the southwesterly movement of the near-surface ground water. This restriction, plus some effect from a diversion dam at this location, results in a high water table condition throughout the lower portions of North Fork Pit River Valley.

Ground water appears to move westerly into the lower Pine Creek area from the extensive upland recharge area of Plio-Pleistocene basalt in the upper Pine Creek and Plum Creek drainage areas. Most of the water recharged from the Fitzhugh Creek area probably moves westerly toward that portion of South Fork Pit River Valley near Signal Butte. Ground water in the Plio-Pleistocene basalt and alluvial fan deposits along the remainder of the east side of South Fork Pit River Valley apparently moves westerly toward the valley floor. Along the west side of the valley, precipitation infiltrates the basalt, then moves generally easterly toward the valley floor through the underlying Alturas formation.

Within the valley floor area of South Fork Pit River Valley, ground water moves in a northerly direction toward Alturas. South of Signal Butte there is considerable ground water recharge from irrigation water and from the East Side and West Side canals. There appears to be a partial restriction to the northerly movement of the near-surface ground water near an

exposure of Warm Springs tuff northwest of Signal Butte. The effect of this partial restriction is to maintain a very flat ground water gradient and a generally high water table condition throughout the portion of the valley south of Signal Butte.

North of the City of Alturas, the Alturas formation is recharged from the lavas of Devils Garden. The direction of ground water movement within this ground water body is southwesterly to westerly. Several municipal wells of the City of Alturas intercept this ground water body. An overlying near-surface ground water body in this same area is recharged by infiltration of surface runoff from adjacent areas of impermeable tuff. A ground water depression occurs in this area because recharge is insufficient to meet the extractions from this upper ground water body.

For lands located west of the confluence of the two forks of Pit River and within the respective drainage areas of Pit River and Rattlesnake Creek, the near-surface ground water moves toward and is intercepted by these streams. All near-surface ground water in the vicinity of Alturas tends to move toward the confluence of the two forks of Pit River. Most of the ground water subsequently rises to the surface and flows out of the subbasin by way of Pit River. Exposures of Warm Springs tuff in Sections 10 and 15, Township 42 North, Range 11 East, M.D.B.&M., act as a partial barrier to the westward movement of ground water from South Fork Pit River Valley subbasin to Warm Springs Valley subbasin.

Warm Springs Valley Subbasin. The general direction of movement of near-surface ground water along the northern side of Warm Springs Valley subbasin is from the recharge areas in the Devils Garden southerly toward Pit River. Blacks Canyon and the lower portion of Clover Swale locally modify this generally southerly direction of movement. Along the south side of Warm Springs Valley, the general direction of movement is northerly

from the recharge areas of Plio-Pleistocene basalt toward Pit River. Again, as along the northern side of the valley, topographic depressions locally alter this movement pattern. Ground water within the Hot Creek drainage area is separated from the near-surface ground water in the remainder of Warm Springs Valley by a barrier of Warm Springs tuff. Ground water in the Hot Creek drainage area apparently moves southerly toward Pit River. Along the east side of Warm Springs Valley, a generally westerly movement of near-surface ground water prevails.

Two partial restrictions to the movement of near-surface ground water occur in Warm Springs Valley. One is Rattlesnake Butte which deflects the southerly movement of ground water. The other is the outcrop area of Warm Springs tuff in Sections 32 and 33, Township 42 North, Range 10 East, M.D.B.&M. This tuff restricts the westerly movement of near-surface ground water and accounts for the flat water table found to the east. It probably has little effect on underlying, deeper aquifers.

No analysis of ground water movement can be made of the deeper, confined aquifers in Warm Springs Valley subbasin, as these aquifers are essentially undeveloped. The ground water in these aquifers probably moves very slowly.

Present Use of Ground Water

For the present level of development, 33,000 acres of the 76,500 acres of valley floor lands in the Alturas ground water basin are irrigated by surface water supplies. The available irrigation supplies from surface water development have, in part, eliminated the need for extensive development of available ground water supplies for irrigation purposes. Of the 286 wells located within the basin, only 14 are irrigation wells, 5 are municipal wells of the City of Alturas, and the majority of the remainder

are used for domestic and stock-watering purposes. The reported yields from the irrigation wells range from about 300 gallons per minute to in excess of 1,000 gallons per minute. The municipal wells yield from 200 to 1,000 gallons per minute, averaging around 400 gallons per minute. Wells for domestic and stock purposes usually have lower yields.

Ground Water Development Potential

Within the Alturas ground water basin all four zones of potential for development of ground water are present. The areas in each classification are shown on Plate 9. The general conditions which presently govern the potential for development of ground water within each zone found in this basin are discussed below.

"A" Zone. The "A" Zone areas are situated at locations where permeable beds of the Alturas formation are exposed at the ground surface or are overlain by a relatively thin mantle of Recent valley sediments. In addition, some of these areas contain buried lava flows which if sufficiently permeable could be producers of confined ground water. Under present conditions of development the existing potential for recharge is more than adequate to provide for anticipated agricultural requirements for water within the "A" Zone areas.

"B" Zone. Most of the irrigable lands in the Alturas ground water basin are included in the "B" Zone areas. With the exception of the "B" Zone area near Parker Creek, the primary difference between the "B" Zone areas and the "A" Zone areas is the apparent lower recharge opportunity for the "B" Zone areas. This may result in local overdraft conditions which in turn would cause increased pumping lifts and decreased yields.

The "B" Zone area near Parker Creek is composed of intermediate alluvium and relatively thick near-shore deposits underlain by the Alturas formation at depth. Recharge of ground water is from infiltration of surface water along the various streams in this area and from precipitation on the near-shore deposits and the lavas to the north. Although the near-shore deposits are generally somewhat less permeable than the Alturas formation, the combination of thickness of the deposits and good recharge opportunity should allow properly constructed deep wells in most of this area to yield moderate quantities of ground water.

"C" Zone. The "C" Zone areas in much of the Alturas basin are those in which the thickness or permeability of the water-bearing materials is limited or the extent of adjacent recharge areas is restricted. The "C" Zone areas situated in Warm Springs Valley subbasin and to the west of the City of Alturas are so classified because the relatively impermeable Warm Springs tuff is found at shallow depths. This tuff is generally a poor producer of ground water and may be up to several hundred feet in thickness. Hence, well yields will be determined by the thickness of the saturated zone in the overlying materials. In certain areas, wells could be constructed through this tuff and into underlying water-bearing materials. The "C" Zone area north of Parker Creek is comprised primarily of near-shore deposits and intermediate alluvium. These materials are usually underlain by impermeable rocks of the Cedarville series. These conditions, along with a relatively poor recharge opportunity, result in this zone being a relatively poor area for the development of ground water.

"D" Zone. The "D" Zone areas are located adjacent to outcrops of rocks having low permeabilities. Because water-bearing surface materials in these areas are underlain at shallow depths by rock of markedly less

permeability, wells located in the "D" Zone areas would yield only small amounts of water. There is also a distinct probability that a well constructed in a "D" Zone area would be dry.

General. The Alturas formation is the most important geologic formation with regard to ground water development potential within Alturas basin. The sedimentary portions of the formation, if sufficiently recharged, usually are capable of yielding moderate to large quantities of ground water to wells. Except in the areas where the Warm Springs tuff is either exposed at the ground surface or underlies the valley floor at shallow depths, the sedimentary portion of the Alturas formation is adjacent to good recharge areas. In general, the degree of ground water development potential at any location within the valley floor is determined by the depth of the sedimentary portions of the Alturas formation underlying the particular location. Within certain areas, permeability and recharge potential are excellent. Here, properly constructed wells should yield large quantities of ground water.

Ground Water Storage Capacity

The ground water storage capacity to a depth of 800 feet in Alturas basin has been estimated to be approximately 7,500,000 acre-feet. How much of this quantity is usable, or how much usable storage exists below 800 feet is not presently known. It is reasonable to assume that a significant amount of ground water could be developed.

Quality of Ground Water

The ground water quality in the Alturas ground water basin is generally good and suitable for most beneficial uses. Throughout most of the basin these waters are bicarbonate in character; however, there is a

portion of Warm Springs Valley subbasin south of the Pit River where additional sulfate and chloride ions are present and the waters have a more balanced anion composition. The cation content of the ground water is predominantly calcium in the vicinity of Alturas and sodium in the area of Warm Springs Valley subbasin east of Canby and north of the Pit River. Elsewhere in the basin the character varies from calcium to sodium.

Water Quality Problems

The most significant water quality problem in this basin is the large area of sodium type waters in Warm Springs Valley subbasin shown on Plate 9. These waters have excessive sodium adsorption ratios and are considered hazardous for irrigation use, although generally suitable for domestic use.

Kelly Hot Springs also pose a water quality problem, as they produce a sodium sulfate water which is poor in quality. Analyses indicate that this water contains a high concentration of total dissolved solids and excessive boron and fluoride. This water is not recommended for irrigation or domestic use.

A few wells scattered throughout Alturas basin contain waters high in nitrate, iron, or boron. The variation of water quality as well as the scattered location of these occurrences of poor quality water indicate that the impairments are of a local nature.

Conclusion

Alturas ground water basin apparently has a significant potential for additional ground water development from aquifers within the Alturas formation. Development of these aquifers in Warm Springs Valley should be done only under the awareness of the possible water quality problem which exists within a portion of this area.

Within the valley floor lands of the Alturas basin, the present requirement for additional irrigation water is highly variable. Within some areas, direct precipitation is the only source of agricultural water, while other areas receive an adequate supply of irrigation water from surface water augmented by storage facilities. Generally, irrigated lands served by direct diversion from non-regulated and some partially regulated streams require supplemental irrigation water sometime after the middle of July. If additional acreage were to be put under irrigation, or if crops requiring increased and/or firmer quantities of irrigation water were planted, an additional source of firm irrigation water would be required in some areas presently considered to possess a good irrigation water supply.

Under the present level of agricultural development, the areas possessing the best ground water development potential are also the areas where additional irrigation water is generally not needed. This inverse supply-requirement condition generally exists throughout most of the area of irrigable valley lands. Except within areas underlain by poor quality ground water, lands requiring a supplemental irrigation water supply, generally can obtain this supply from ground water, but wells constructed for this purpose generally will not be located within areas of best ground water development potential.

It is concluded that the basic data collection activities of the Department of Water Resources should be continued in order to facilitate future quantitative and qualitative analysis of the ground water basin. Encouragement should be offered to local agencies in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

Big Valley and Round Valley Ground Water Basins

Big Valley consists of a broad plain about 13 miles long from north to south, and 15 miles wide from east to west. The northern portion is in Modoc County and the southern portion in Lassen County. Big Valley is bordered by extensive bench lands and gently sloping hills. Surrounding mountains include the Big Valley Mountains to the west, and Barber Ridge to the east. The elevation of the floor of Big Valley is about 4,200 feet. Pit River enters Big Valley from the north and flows southerly across the valley past the towns of Lookout and Bieber. The river leaves the valley by way of a gorge at its southern end.

Round Valley is located to the northeast of Big Valley and is considerably smaller in area and slightly higher in elevation than Big Valley. Round Valley is entirely surrounded by mountains. The principal mountains are Horsehead Mountain to the northeast, and Barber Ridge to the southeast, separating Round Valley from Big Valley. Ash Creek enters Round Valley from the southeast. It joins Rush Creek in the central portion of the valley and then flows westward into Big Valley.

The surface exposures of the various geologic formations of the Big Valley and Round Valley area are shown on Plate 10, Areal Geology, Big Valley and Round Valley Ground Water Basins. Plate 11, Generalized Lines of Equal Elevation of Water in Wells in Near-Surface Aquifers, Big Valley and Round Valley Ground Water Basins, Spring 1960, is a generalized picture of the elevation of unconfined or semi-confined ground water within the ground water basins. Plate 12, Generalized Lines of Equal Elevation of Water in Wells in Confined Aquifers, Big Valley and Round Valley Ground Water Basins, Spring 1960, indicates the general elevation to which

confined ground water would rise in a well. Plate 13, Potential for Development of Ground Water, Big Valley and Round Valley Ground Water Basins, presents the preliminary evaluations of the potential for ground water development within these basins.

Geologic History

Rocks exposed in Big Valley and Round Valley record geologic history dating back to the Miocene epoch, 25 million years ago. During the Miocene and Pliocene epochs, these valleys were part of an area of extensive lakes bordered by large volcanoes. The lakes received large volumes of ash and other volcanic debris blown into the water by violent explosions and washed in by torrential rains. During the latter part of the Pliocene epoch, the crust of the earth began shifting along numerous faults. Vertical movement along these faults slowly built the mountains surrounding the present valleys and caused the valley areas to sink. The lakes which were present were restricted more or less to the present valley areas and the low-lying area north of Lookout. During the same epoch, masses of rhyolite lava formed domes southeast of the valley. By the end of the Pliocene epoch, the ancient Pit River had succeeded in cutting through the Big Valley Mountains and had drained the remnants of the Pliocene lake.

During Pleistocene time, extensive flows of basalt spread over parts of the old lake bed and formed the low-lying plateau north of Big Valley. Similar flows covered the southern portion of the valley and filled the ancestral canyon of Pit River. The resulting natural dam flooded Big Valley forming another large lake. This lake remained throughout the Pleistocene epoch and possibly was present in the early part of the Recent epoch. Pit River eventually cut through the basalt barrier and drained

the lake. The barrier still has not been completely removed as illustrated by the large swampy areas found in Big Valley today.

Water-Bearing Formations

Table 11 briefly describes the geologic formations in Big Valley and Round Valley. Of these, the principal water-bearing formations are Pliocene to Pleistocene lava flows, the Bieber formation, and Recent valley sediments.

Pliocene to Pleistocene Lava Flows. Pliocene to Pleistocene lavas consist of jointed and fractured basalt and occur both north and south of Big Valley. They also cap Barber, Ryan, and Hunter Ridges above Round Valley. The lavas are in general moderately to highly permeable and act as forebays for ground water recharge. Near the south end of Big Valley, in the vicinity of Juniper Creek, a Pleistocene basalt flow yields moderate amounts of artesian water to wells and sumps. No well data are available for the basalt flows at the northern end of the valley. These latter flows may yield moderate to large amounts of ground water where there is an appreciable saturated thickness. From Lookout northward along Pit River, the basalts appear to be mostly above the zone of saturation and apparently are too thin to yield large amounts of ground water.

Bieber Formation. The Bieber formation underlies all of Big Valley and Round Valley, in many places beneath a thin veneer of younger deposits, and also occurs beneath some of the adjacent basalt flows. The Bieber formation consists of lake deposited diatomite, sand, silt, clay, and some gravel. Its thickness is estimated to be at least 1,000 feet and in some areas may be as much as 2,000 feet. It apparently grades downward into underlying diatomaceous sediments of the Turner Creek formation. The principal aquifers in the Bieber formation consist of beds of white pumiceous

TABLE II

GEOLOGIC FORMATIONS
IN BIG VALLEY AND ROUND VALLEY AREA

GEOLOGIC AGE			GEOLOGIC FORMATION	STRATIGRAPHY	APPROXIMATE THICKNESS IN FEET	PHYSICAL CHARACTERISTICS	WATER-BEARING CHARACTERISTICS
CENOZOIC	QUATERNARY	RECENT	BASIN DEPOSITS	Qb	0-150	Qb: Unconsolidated, interbedded silt, clay, and organic muck. Alkali may be present.	Low permeability. Yields small amounts of water to wells.
CENOZOIC	QUATERNARY	RECENT	INTERMEDIATE ALLUVIUM	Qal	0-150	Qal: Unconsolidated, poorly sorted silt and sand containing minor amounts of clay and gravel. Alkali may be present.	Moderately permeable. Yields moderate quantities of water to wells.
CENOZOIC	QUATERNARY	RECENT	ALLUVIAL FANS	Qf	0-150	Qf: Unconsolidated, rudely stratified gravel, sand, and silt, with clay lenses.	Moderately permeable; may contain moderate amounts of free and confined water.
CENOZOIC	QUATERNARY	PLEISTOCENE	PLEISTOCENE BASALT	Qpvb	50-150	Qpvb: Highly jointed, vesicular, flat-lying olivine basalt flows; contains scoria zones.	Permeability ranges from moderate to high. Acts as recharge area for ground water in Big Valley. Yields moderate to large quantities of free and confined water to wells in southern part of Big Valley.
CENOZOIC	QUATERNARY–TERTIARY	PLEISTOCENE–PLIOCENE	BIEBER FORMATION	TQb	0-1,000	TQb: Unconsolidated to semi-consolidated, interbedded diatomite, silt, sand, and some gravel. Apparently grades downward into Turner Creek formation.	Generally of moderate permeability. Yields moderate quantities of water to wells.
CENOZOIC	TERTIARY	PLIOCENE	PLIOCENE VOLCANIC ROCKS: BASALT	Tpvb	1,000	Tpvb, Tpva: Flows of jointed basalt and andesite.	Moderately permeable. Basalt acts as forebay for recharge to adjacent parts of Big Valley and Round Valley. May yield moderate quantities of water to wells. Andesite is essentially impermeable.
CENOZOIC	TERTIARY	PLIOCENE	PLIOCENE VOLCANIC ROCKS: ANDESITE	Tpva			
CENOZOIC	TERTIARY	MIOCENE TO PLIOCENE	RHYOLITE	Tvr	?	Tvr: Light-colored rhyolite and rhyolite tuff.	Essentially impermeable.
CENOZOIC	TERTIARY	MIOCENE TO PLIOCENE	BIG VALLEY MOUNTAINS VOLCANIC SERIES	Tvb	4,000	Tvb: Jointed, dipping flows of basalt with interbeds of sand, tuff, and diatomite. May be equivalent in part to Turner Creek formation.	Low overall permeability. Some basalt flows may yield small to moderate amounts of water.
CENOZOIC	TERTIARY	MIOCENE	TURNER CREEK FORMATION	Tmtc	4,000	Tmtc: Well bedded sand, silt, diatomite, tuff, and mudflows; minor flows of basalt, andesite.	Generally low permeability but contains some permeable beds which yield small to moderate quantities of water to wells.

sand and black volcanic sand. These sands are highly permeable and occasionally are capable of yielding up to 1,000 gallons per minute to wells. However, the beds are usually too thin to yield such large amounts of water. Individual beds are laterally discontinuous, but they occur beneath most parts of the valleys.

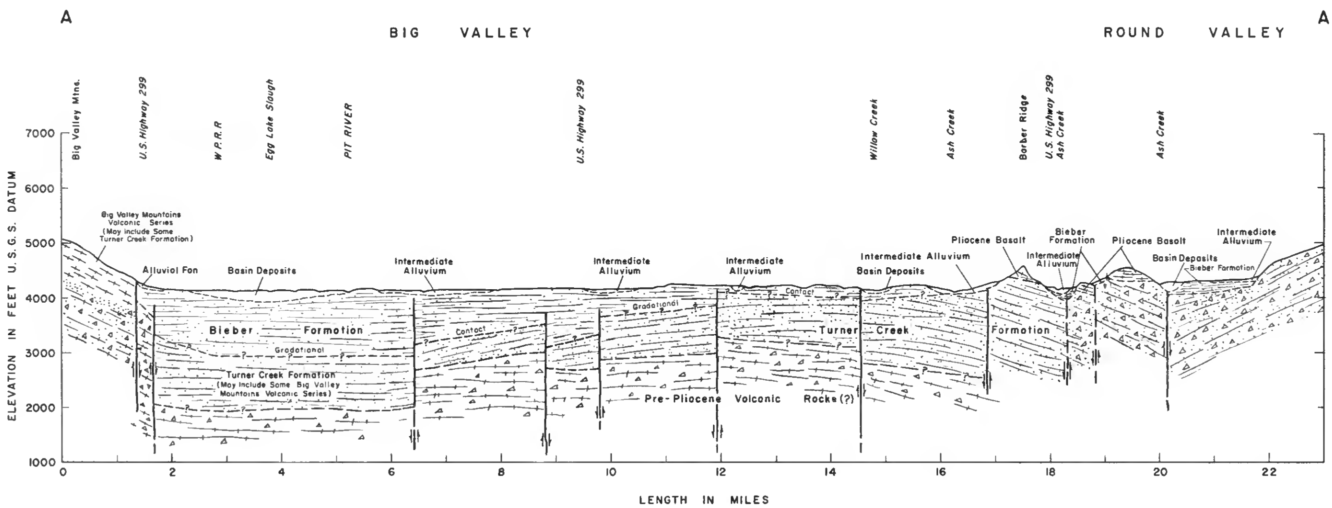
Recent Valley Sediments. Recent valley sediments in Big and Round Valleys include basin deposits, intermediate alluvium, and alluvial fans. The basin deposits consist mainly of organic muck, silt, clay, and some sand. They occupy the low-lying, poorly drained areas. The deposits are of low permeability and do not yield appreciable amounts of water to wells.

The intermediate alluvium consists of up to about 200 feet of sand and silt with lenses of gravel and clay. These deposits occupy more elevated, better drained portions of the valleys. The intermediate alluvium is generally of moderate permeability but may be highly permeable where large gravel lenses occur. In areas where the intermediate alluvium is of sufficient thickness, it may provide large yields of water to irrigation wells.

The alluvial fans occur in only a few small areas in the two valleys. The fans consist of poorly bedded gravel, sand, silt, and clay. The fans are not important water producers in this area. They may, however, locally yield moderate amounts of water to wells.

Influence of Geologic Structure on Ground Water

The geologic structure of Big Valley and Round Valley is that of a series of depressed fault-blocks surrounded by uplifted tilted fault-block ridges as shown on Plate 10 and Figure 13. Subsurface features shown on Figure 13, as well as locations of many faults in Big Valley, as shown on



See Plate 10 for location of section.

Figure 13. GENERALIZED GEOLOGIC SECTION A-A'
BIG VALLEY AND ROUND VALLEY GROUND WATER BASINS

Plate 10, are from interpretation of data from a geophysical survey of the valley floor area of Big Valley and from exploratory test holes drilled in Big Valley. Figure 14 was developed from well log data.

The main fault trend is to the northwest with a subordinate system trending to the northeast. The fault-blocks forming the Big Valley Mountains, Barber Ridge, and Ryan Ridge are tilted to the east. The Bieber formation has been deformed into gentle folds apparently associated with faulting in Big Valley. The ridge east of Round Valley has been deformed into a broad arch.

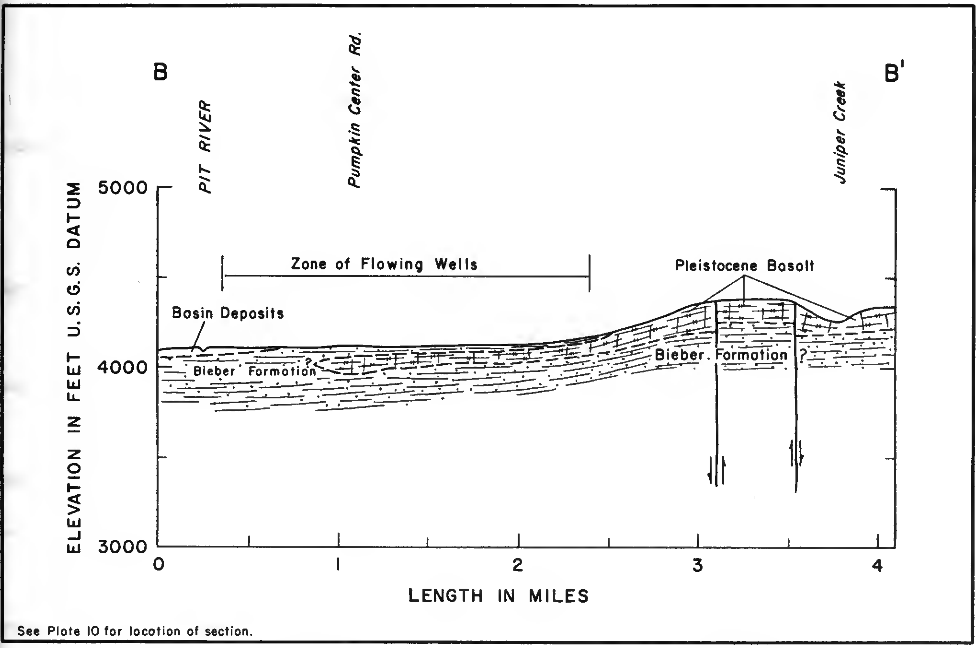


Figure 14. GENERALIZED GEOLOGIC SECTION B-B'
BIG VALLEY GROUND WATER BASIN

The numerous faults may act as partial ground water barriers, although in a few places they serve as paths for the upward migration of heated ground water. Fault barriers to ground water movement are formed by offsetting permeable beds and by the creation of impervious gouge along the fault plane. Ground water is often forced to the surface along these barriers, forming springs. Many springs of this type are found in the area. The two hot spring areas in Big Valley are located close to faults. The hot springs are formed as a result of deep circulating ground water becoming heated and mixing with mineralized upward moving water of probable magmatic origin.

Recharge and Movement of Ground Water

Upland recharge areas are shown on Plates 11 and 12. Ground water within the sediments of Big Valley and Round Valley is recharged primarily from the upland recharge areas of Pliocene and Pleistocene basalt located south and northwest of Big Valley and west of Round Valley. The upland recharge area shown to the north of Round Valley and indicated as indeterminate on the plates consists of a portion of the Turner Creek formation. At this location, permeable beds in the Turner Creek formation dip toward the south and apparently pass beneath the valley floor. Ground water contained in these beds appears to recharge the sediments in the northern portion of Round Valley. In both valleys, a secondary, but highly significant amount of recharge is derived from surface water infiltrating the Recent sediments along the numerous streams which flow into and through the valleys.

The mean seasonal precipitation on the floor of Big Valley ranges from less than 10 inches near Hot Springs triangulation station, to in excess of 18 inches near the margin of the valley floor. The year to year variation of precipitation is considerable. At Bieber, the mean seasonal

precipitation is 16.77 inches, but the recorded maximum and minimum precipitation is 28.24 and 8.69 inches, respectively.

Mean seasonal precipitation on the upland recharge areas is also subject to considerable variation, the maximum and minimum values being somewhat higher than those of the valley floor. The mean seasonal precipitation over most of the upland recharge areas ranges from 18 to 22 inches.

On the floor of Round Valley, the mean seasonal precipitation is about 16 inches. The size of the valley floor apparently is not sufficient to cause a significant change of precipitation from one side of the valley floor to the other, although precipitation from thunder storms is quite variable. Long-term maximum and minimum precipitation values are not available for any station within Round Valley, but the magnitude of these variations should approximate those of stations in Big Valley.

Upon the recharge areas to the west of Round Valley, the mean seasonal precipitation is estimated to range from 18 to 24 inches. Here, as in other nearby upland recharge areas, the variation of precipitation from year to year is considerable.

Generalized lines of equal elevation of water in wells within Big Valley and Round Valley are shown on Plates 11 and 12. The lines on Plate 11 indicate the general direction of movement of the near-surface ground water body underlying most of the valley floor areas. This body is presently intercepted by wells of depths generally less than 70 feet. The lines on Plate 12 indicate movement for a portion of a deeper, confined ground water body within Big Valley. This body is generally intercepted by wells of depths generally in excess of 200 feet. A discussion of the movement of ground water within each of these basins is given below.

Big Valley Ground Water Basin. Within the portion of the valley floor near Adin, near-surface ground water moves toward Ash Creek where it is partly intercepted. In areas where this ground water body occurs within the Bieber formation, it is under various degrees of confinement. Where it is in the intermediate alluvium and basin deposits, it is in an essentially unconfined state. To the west of the confluence of Ash Creek and Willow Creek, the direction of movement of this ground water body is westerly toward Pit River.

The direction of movement of the upper ground water body north of Lookout is generally from the surrounding foothills toward Pit River. Between Lookout and Bieber, a portion of the ground water is intercepted by numerous stream channels, and the remainder moves southerly toward Bieber under a relatively flat gradient.

The two areas with lines of equal elevation of water in wells shown on Plate 12 in the vicinity of Bieber and Adin, generally represent the piezometric surface of a combination of various confined ground water bodies. In the area generally south of Juniper Creek, these lines apparently represent the piezometric surface of confined ground water moving southwesterly in a buried lava flow and an underlying permeable sand bed of the Bieber formation. Recharge to this ground water body is apparently from the basalts along Juniper Creek. The lines in the vicinity of Bieber apparently represent the piezometric surface of confined ground water within certain permeable beds of the Bieber formation. Location and method of recharge to the deeper aquifers in this area are uncertain.

Near Adin, a few wells intercept a confined ground water body. The direction of movement in this body is apparently toward the west.

There appear to be several separate ground water bodies within the Bieber formation which are not included in the representations

on Plates 11 and 12. In addition to these bodies, a relatively small quantity of mineralized ground water rises along faults in particular areas.

Round Valley Ground Water Basin. East of Ryan Ridge, the direction of movement of the near-surface ground water is generally similar to that of the surface streams. As in Big Valley, the degree of confinement varies from locally confined zones in the Bieber formation to essentially unconfined conditions within the intermediate alluvium and basin deposits. Deeper ground water bodies, not included in the representations on Plate 11, also exist within this portion of Round Valley. These bodies are confined and cause wells in some areas to flow.

South of Ryan Ridge, the near-surface ground water presently intercepted by wells is moving in a southeasterly direction from the Pliocene basalt of Barber Ridge toward Ash Creek. The Turner Creek formation of Ryan Ridge is a barrier between ground water moving downslope through Barber Canyon and ground water in the remainder of the valley. There is hydraulic continuity between these two ground water bodies in the immediate vicinity of Ash Creek, at the mouth of Barber Canyon. Some subsurface movement of ground water from Round Valley toward Big Valley exists through the narrows of Ash Creek near Adin.

Present Use of Ground Water

The valley floor of Big Valley comprises 93,500 acres, about 88,000 acres of which are classified as irrigable. Approximately 24,000 acres are currently irrigated during the early spring by waters diverted from unregulated or partially regulated streams. As frequent flooding also occurs during this portion of the growing season, the type of crops grown on the irrigable lands of the lower portion of the valley floor are limited to those possessing a tolerance to annual inundation and prolonged high water

table conditions. During the latter portion of the growing season, surface water irrigation supplies usually are insufficient to maintain optimum soil moisture conditions. Ground water development for the purpose of supplemental irrigation water supply has been attempted with various degrees of success within the valley. During 1958 only 140 acres of cultivated crops received their total or partial irrigation water supply from pumped ground water. However, several of the irrigation wells were inoperative during 1958, the year the survey of irrigated lands was conducted. The approximate yields of 16 irrigation wells located during 1957 ranged from 190 to 900 gallons per minute, usually with considerable drawdown. Of the 420 wells located during this period, the majority of the active wells were utilized for domestic and stock watering purposes.

Most of the irrigated lands within Round Valley receive irrigation water from gravity diversion of the unregulated flow of Ash Creek and Rush Creek. The irrigation water supply for most of the remainder of the irrigated lands is either from springs or from four flowing wells. The acreage irrigated by flowing wells is estimated to be approximately 10 acres. The above irrigated lands comprise only a small portion of the irrigable lands within the 8,300 acres of the valley floor of Round Valley.

Most wells located in Round Valley are used either for domestic or stock watering uses. Only the four flowing wells were used for irrigation purposes during 1957. The yield from each of these flowing wells is approximately the same and is estimated to be about 10 gallons per minute.

Ground Water Development Potential

Within the valley floor area of Big Valley and Round Valley ground water basins, three of the four zones of potential for development of ground water are present. The area of the valley floor in each of the three

classifications is shown on Plate 13. The general conditions which govern the potential for development of ground water within each zone found in this basin are discussed below.

Big Valley "B" Zone. The southernmost of the three "B" Zone areas of ground water development potential within Big Valley apparently contains numerous sand beds of the Bieber formation. There is also the possibility that a thin, buried permeable lava flow may extend into the eastern part of this area. It appears that there is adequate recharge to the water-bearing materials in this area.

The "B" Zone area near Lookout is composed of coarse intermediate alluvial materials deposited by Pit River and Taylor Creek. The depth of these materials is probably about 200 feet. Underlying these materials are lake deposits of low permeability belonging to the Bieber and Turner Creek formations.

The "B" Zone area along Widow Valley Creek is composed of coarse stream deposits up to 100 feet in thickness. Recharge to ground water within the two northerly "B" Zone areas is from infiltration of surface water along the stream channels and by subsurface movement from Pliocene and Pleistocene lavas located north of the areas.

Yields of properly constructed wells within the "B" Zone areas are expected to vary considerably because of variations in thickness and number of permeable beds intercepted, and because of differences in permeability and recharge opportunity of the individual beds.

Big Valley "C" Zone. Most of valley floor lands in Big Valley are classified as a "C" Zone area. The geologic materials within this area are primarily lake deposits belonging to the Bieber formation which are overlain in part by a relatively thin mantle of Recent sediments. The overlying sediments are frequently too thin to yield substantial quantities of

ground water to wells. The number of sand beds in the Bieber formation is apparently less than in the "B" Zone area south of Bieber, considerably reducing well yields in the area classified as "C" Zone. In the vicinity of Juniper Creek, there is a permeable basalt flow interbedded with sediments of the Bieber formation. This lava is apparently relatively thin and probably would not produce large quantities of ground water to wells. Recharge available to the "C" Zone area from infiltration of surface water and from lateral movement from surrounding lava areas probably exceeds the quantity of ground water which the aquifers can transmit to wells in the valley floor area. Therefore, the expected yields of wells in this area generally are sufficient only for domestic, stockwatering, and limited irrigation uses.

Big Valley "D" Zone. The "D" Zone areas are located adjacent to areas of impermeable rock. The intermediate alluvium, alluvial fan, and lavas found in the "D" Zone areas are permeable but because they are underlain at shallow depths by impermeable rock, wells in these areas would yield only small amounts of ground water.

Big Valley Contiguous Areas. Wells drilled in certain portions of the upland recharge areas could yield moderate to large quantities of ground water, depending on the permeability of the materials intercepted. Within particular portions of the upland recharge areas, ground water yields may be greater than those of wells drilled in the valley floor. The depth to ground water, however, is generally greater in the upland areas than in the valley floor areas.

Round Valley "B" Zone. The "B" Zone area in the vicinity of the confluence of Rush Creek and Ash Creek is composed of coarse intermediate alluvial material deposited by these streams. The depth of these materials may be about 150 feet. Underlying these materials are less permeable lake

deposits belonging to the Bieber and Turner Creek formations. Recharge to ground water in this area is apparently from infiltration of surface water along the stream channels.

Round Valley "C" Zone. Most of valley floor lands in Round Valley are classified as a "C" Zone area. The geologic materials in this area consist primarily of lake deposits belonging to the Bieber formation which are overlain by thin deposits of Recent sediments. Ground water yields from wells in this area will depend primarily upon the thickness of the intercepted permeable beds.

Recharge of ground water in this area is from infiltration of surface water and from percolation from adjacent upland recharge areas. As in Big Valley, the recharge opportunity to ground water within this area is apparently better than the ability of the aquifers to transmit ground water.

Round Valley "D" Zone. The "D" Zone areas are located adjacent to areas of impermeable rock. The intermediate alluvium and alluvial fans within these areas are quite permeable, but they appear to be too thin to yield any substantial quantities of ground water.

General. In the valley floor area of both Big Valley and Round Valley ground water basins, the potential for development of wells with yields sufficient for irrigation purposes is limited, due to the fact that the developable aquifers are not sufficiently permeable. The potential yield should be sufficient, however, for anticipated demands for domestic and stock purposes in "C" Zones, and may be greater in "B" Zones.

Within portions of the upland recharge area northwest of Big Valley, ground water yields from deep wells probably will exceed the average yield of the deep wells within the valley floor, but the depth to water will generally be greater in these upland areas.

One area of exception to the limited potential for irrigation well development within Round Valley is located near the confluence of Ash Creek and Rush Creek. Here a limited number of properly constructed irrigation wells probably could be located and developed. However, too heavy development in this area would result in falling ground water levels.

Ground Water Storage Capacity

The ground water storage capacity to a depth of 1,000 feet has been estimated in Big Valley to be approximately 3,750,000 acre-feet. Storage capacity in Round Valley has been estimated to be 120,000 acre-feet to a depth of 200 feet. How much of these quantities are usable or how much storage exists below the depths of 1,000 and 200 feet, respectively, is not presently known. It is reasonable to assume that a significant amount of ground water could be developed.

Quality of Ground Water

Ground waters in Big Valley and Round Valley are generally excellent in mineral quality and suitable for most beneficial uses. Bicarbonate is generally the predominant anion in these waters. The cations are usually well balanced although sodium predominates in some well waters. The sodium type waters are found scattered throughout the valleys rather than in a particular portion of the basin.

Two hot springs and one well in Big Valley basin yield poor quality thermal waters. The well and one of the springs are located about 6 miles east of Bieber. The other spring is located 2-1/4 miles northeast of Bieber. These poor quality waters are sodium sulfate in character and are not recommended for either domestic or irrigation use.

Water Quality Problems

The most significant water quality problem in Big Valley is that posed by the poor quality thermal waters found in the hot springs areas. These waters have high electrical conductivities and excessive concentrations of fluorides and boron. They are considered as hazardous for either domestic or irrigation use. These poor quality waters can impair adjacent ground or surface waters if they are discharged freely at the ground surface or if they are permitted to migrate into them through improperly constructed or abandoned wells.

One well located 3-1/2 miles west of Adin produces water containing arsenic in concentrations exceeding 0.1 ppm. This water does not meet drinking water standards and is not recommended for domestic use. This occurrence is apparently localized and the concentration is low enough that it could be reduced to a safe level through dilution.

Ground waters extracted from several wells scattered throughout the basin contain excessive nitrates and are considered to be hazardous for domestic use. These occurrences appear to be the result of localized impairment.

Conclusion

Ground water development for irrigation purposes by deep irrigation wells within Big Valley and Round Valley appears to be limited by the generally low permeability of aquifers within the Bieber formation. Ground water of good quality is available except in certain localized areas where hot springs or isolated wells produce waters of poor quality.

It is concluded that the basic data collection activities of the Department of Water Resources should be continued in order to facilitate future quantitative and qualitative analyses of the ground water basin. Encouragement should be offered to local agencies in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

Fall River Valley Ground Water Basin

Fall River Valley is located in eastern Shasta County and western Lassen County. The valley is about 7 miles long and 16 miles wide and lies at an elevation of about 3,300 feet. It is bounded on the east by the Big Valley Mountains and on the west by a ridge consisting of Soldier and Saddle Mountains. The northern and southern boundaries are poorly defined because of extensive lava flows of low relief. Fall River is the major stream draining the valley. It flows in a southerly direction to its confluence with Pit River near the town of Fall River Mills, in the southwestern part of the valley. Pit River enters the valley on the southeast. It flows past the towns of Pittville and McArthur to its confluence with Fall River and then flows southwesterly out of the valley. There are only a few tributary creeks in the valley. One is Bear Creek in the northwestern part of the valley, the other is Beaver Creek in the southeastern portion.

The surface exposures of the various geologic formations of the Fall River Valley area are shown on Plate 14, Areal Geology, Fall River Valley Ground Water Basin. Plate 15, Generalized Lines of Equal Elevation of Water in Wells in Aquifers, Fall River Valley Ground Water Basin, Spring 1960, presents a generalized picture of the elevation of ground water within the ground water basin. Plate 16, Potential for Development of Ground Water, Fall River Valley Ground Water Basin, presents the preliminary evaluations of the potential for ground water development within this basin.

Geologic History

During the Miocene epoch, Fall River Valley was the scene of many volcanic eruptions. For millions of years, lava and ash accumulated layer upon layer, creating a broad volcanic plateau. During the late Pliocene and

early Pleistocene epochs, recurrent earthquakes broke and uplifted the eastern part of the plateau to form the Big Valley Mountains; the western part sank to form Fall River Valley. The valley was soon occupied by a large lake which originally may have drained to the north into Klamath River. Near the end of the Pleistocene epoch, volcanism north of Fall River Valley produced lavas which covered the northern end of the valley. Subsequently, the lake overflowed through a gap at the southwestern edge of the valley. Erosion of this outlet eventually drained the lake, carved Pit River Canyon, and left the valley much as we see it today.

Water-Bearing Formations

Table 12 briefly describes the geologic formations in Fall River Valley. Of these, the principal water-bearing formations are Pliocene to Recent lava flows, lake and near-shore deposits, and Recent valley sediments.

Pliocene to Recent Lava Flows. Basalt flows of Pliocene to Recent age are usually highly fractured and frequently contain many scoria zones; lava tubes are not uncommon in the Recent basalt flows. The overall permeability of the Recent basalt is high to very high. Permeability in the Pleistocene basalt is moderate to high, and it is low to moderate in the Pliocene basalt. This decrease in permeability with an increase in age is due to weathering of the rock to form clay which seals the openings in the rock.

Although there is scant information regarding wells in the various lava flows, the following observations can be made.

Recent basalt partly overlies lake sediments at the northern end of Fall River Valley. A second area of similar Recent basalt is located south of McArthur. Fall River and its associated streams and lakes are fed by

GEOLOGIC FORMATIONS IN FALL RIVER VALLEY

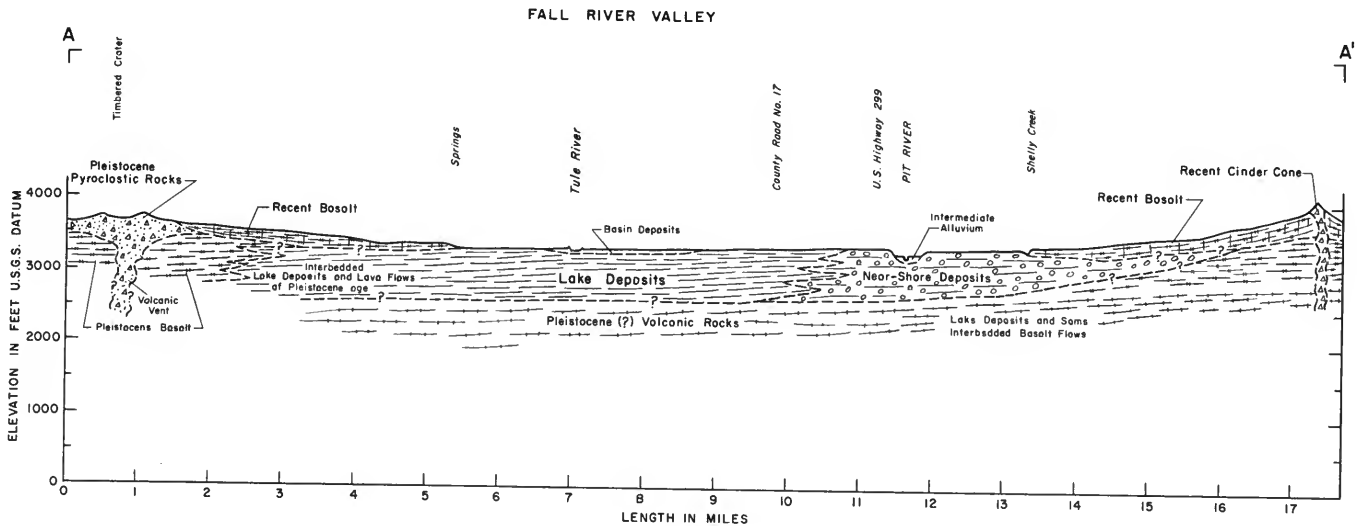
GEOLOGIC AGE			GEOLOGIC FORMATION	STRATIGRAPHY	APPROXIMATE THICKNESS IN FEET	PHYSICAL CHARACTERISTICS	WATER-BEARING CHARACTERISTICS
CENOZOIC	QUATERNARY	RECENT	TALUS	Qta	0-75	Qta: Unconsolidated blocks of rock, of small areal extent.	Highly permeable, but usually above zone of saturation. Yields water to springs.
CENOZOIC	QUATERNARY	RECENT	BASIN DEPOSITS	Qb	0-20	Qb: Unconsolidated clay, peat, and organic muck.	Low permeability, unimportant as source of ground water.
CENOZOIC	QUATERNARY	RECENT	INTERMEDIATE ALLUVIUM	Qal	0-100	Qal: Unconsolidated silt, sand, and gravel along stream channels and on flood plains.	Permeability ranges from moderate to high. May yield moderate quantities of water to shallow wells.
CENOZOIC	QUATERNARY	RECENT	ALLUVIAL FANS	Qf	0-200	Qf: Unconsolidated, poorly stratified gravel, sand, and silt.	Moderately permeable. May contain moderate amounts of free and confined water.
CENOZOIC	QUATERNARY	RECENT	RECENT VOLCANIC ROCKS — BASALT AND CINDER CONES	Qrvb	30-500	Qrvb: Highly jointed, vesicular olivine basalt. Includes cinder cones containing unconsolidated volcanic cinders.	Highly permeable. Acts to recharge north part of valley. Provides copious quantities of water to springs, streams, and lakes at north end of valley.
CENOZOIC	QUATERNARY	PLEISTOCENE	NEAR-SHORE DEPOSITS	Qps	0-300	Qps: Partly consolidated sand, silt, and clay. Frequently cross-bedded and of a bluish color.	Moderately permeable. Yields moderate quantities of water to wells.
CENOZOIC	QUATERNARY	PLEISTOCENE	LAKE DEPOSITS	Qpl	0-700	Qpl: Partly consolidated, interbedded clay, volcanic ash, diatomite, and fine sand. Interfingers with near-shore deposits.	Slightly permeable. Occasional sand beds yield small quantities of water to wells. Acts as confining layers to ground water in buried lava flows.
CENOZOIC	QUATERNARY	PLEISTOCENE	PLEISTOCENE VOLCANIC ROCKS — PYROCLASTIC ROCKS	Qpvp	50-300	Qpvp: Partly consolidated, bedded volcanic cinders.	Highly permeable but of small areal extent and hence unimportant as source of ground water.
CENOZOIC	QUATERNARY	PLEISTOCENE	PLEISTOCENE VOLCANIC ROCKS — BASALT	Qpvb	50-750	Qpvb: Jointed flows of olivine basalt.	Permeability ranges from moderate to high. Yields large quantities of confined water where interbedded with lake deposits.
CENOZOIC	TERTIARY	PLIOCENE	PLIOCENE LAKE DEPOSITS	Tpl	?	Tpl: Horizontally bedded deposits of diatomite, with lesser amounts of sand and gravel. Found only near Lake Britton.	Some beds are moderately permeable; may act as routes of subsurface outflow from valley.
CENOZOIC	TERTIARY	PLIOCENE	PLIOCENE VOLCANIC ROCKS — ANDESITE	Tpva	?	Tpva: Plugs and domes of platy andesite.	Essentially impermeable.
CENOZOIC	TERTIARY	PLIOCENE	PLIOCENE VOLCANIC ROCKS — BASALT	Tpvb	1000	Tpvb: Flows of basalt with some interbedded pyroclastic rocks.	Low to moderate permeability. May yield small quantities of water.
CENOZOIC	TERTIARY	PLIOCENE	PLIOCENE VOLCANIC ROCKS — PYROCLASTIC ROCKS	Tpvp	?	Tpvp: Beds of tuff.	Essentially impermeable.
CENOZOIC	TERTIARY	MIOCENE TO PLIOCENE	BIG VALLEY MOUNTAINS VOLCANIC SERIES	Tvb	4000	Tvb: Jointed, dipping flows of basalt with interbeds of sand, tuff, and diatomite.	Low overall permeability. Some basalt flows may yield small amounts of water.
CENOZOIC	TERTIARY	MIOCENE	MIOCENE BASALT	Tmvb	1000	Tmvb: Flows of basalt.	Very low permeability. May yield small amounts of water.

numerous springs which occur along the front of the Recent basalt flows at the north of the valley. The presence of large springs is indicative of the high permeability and vast ground water storage capacity of these rocks. According to the United States Geological Survey, five groups of springs in Section 19, Township 38 North, Range 4 East, M.D.B.&M. flow from the Recent basalt and form the headwaters of Fall River. These springs have an estimated combined flow of about 150,000 gallons per minute. Other springs also flowing from these lavas form Spring Creek, Eastman Lake, Tule River, and Big Lake. The total measurable flow of springs issuing from the Recent lavas has been estimated to be about 400,000 gallons per minute.

Most of the Pleistocene basalt found on the east side of the valley appears to be highly permeable. In contrast, portions of the Pleistocene basalt found in other areas have a somewhat lower permeability and an upper surface that is sufficiently impermeable that small reservoirs have been constructed thereon. The principal importance of most of the Pleistocene basalt is as a ground water recharge area. Wells located in this basalt may provide moderate yields for domestic and stock purposes. However, Pleistocene lavas where buried within lake and near-shore deposits may yield large quantities of confined ground water to wells.

The Pliocene basalt provides some ground water recharge to the southern part of Fall River Valley. Although not suitable for irrigation well development, some areas of Pliocene basalt may yield sufficient water to wells for domestic or stock use. In addition, some perched ground water may be found locally in this unit.

Lake and Near-Shore Deposits. Lake deposits, up to 700 feet thick, are found in the northern part of Fall River Valley where they extend some distance northward beneath a cover of Recent basalt as shown on Figure 15.



See Plate 14 for location of section.

Figure 15. GENERALIZED GEOLOGIC SECTION A–A'
FALL RIVER VALLEY GROUND WATER BASIN

Near Pit River, the lake deposits interfinger with the coarser grained near-shore deposits.

The lake deposits as a whole are only slightly permeable. Occasion sand beds yield small quantities of ground water to wells. In contrast, the near-shore deposits are moderately permeable and yield moderate quantities of water to wells. A number of irrigation wells are located in areas of lake and near-shore deposits. These wells yield fair to large quantities of ground water. However, most of the ground water apparently is derived from buried lava flows rather than from lake and near-shore deposits.

Recent Valley Sediments. Recent valley sediments include alluvial fans, intermediate alluvium, and basin deposits. In general, alluvial fans are moderately permeable and serve chiefly as ground water recharge areas. Water cascading down the canyons infiltrates the fans and then percolates valleyward. Wells located on the alluvial fans may yield moderate quantitie of ground water.

Most of the intermediate alluvium in Fall River Valley is too thin to be of major significance to ground water. Only deposits along Bear Creek and Pit River show any promise of substantial ground water development. In these areas the intermediate alluvium may reach a maximum thickness of 100 feet and may yield moderate quantities of ground water to irrigation wel

Overlying the lake deposits in the vicinity of McArthur Swamp and Big Lake are Recent basin deposits which may be up to 20 feet in thickness. The deposits are of little importance as a source of ground water. Any significant amounts of ground water from wells located on basin deposits is derived from underlying materials.

Influence of Geologic Structure on Ground Water

The geologic structure of Fall River Valley is illustrated on geologic sections A-A' and B-B' shown on Figures 15 and 16, respectively. Basically, the valley is a northwest-trending fault trough in which a group of blocks has moved downward between two groups of elevated blocks. The volcanic rocks which underlie the valley also have been tilted and broken into several smaller blocks. There are at least three faults or fault systems passing beneath the lake deposits in Fall River Valley. One fault passes beneath McArthur and has the greatest apparent displacement. The lava flows here have been offset several hundred feet, the west side having moved downward relative to the east side. A group of three parallel faults are located north and west of Glenburn. Rocks on the east side of each of these faults are offset downward about 200 feet. There is no evident displacement along these faults in the Recent lavas north of the valley floor. A third fault branches from a fault along the east side of the valley and continues beneath the valley floor in a northwesterly direction beyond the east end of Big Lake. The total offset along this fault appears to be about 150 feet downward on the west side.

The general effect of faulting in the volcanic rocks has been the creation of shattered permeable zones which may serve as vertical and/or lateral paths for ground water movement. Because the sediments in Fall River Valley are essentially horizontally bedded, these percolation paths may be of great importance to the recharge of the deep aquifers in the valley. On the other hand, faulting within the sedimentary deposits may tend to create ground water barriers by realigning beds of different permeabilities.

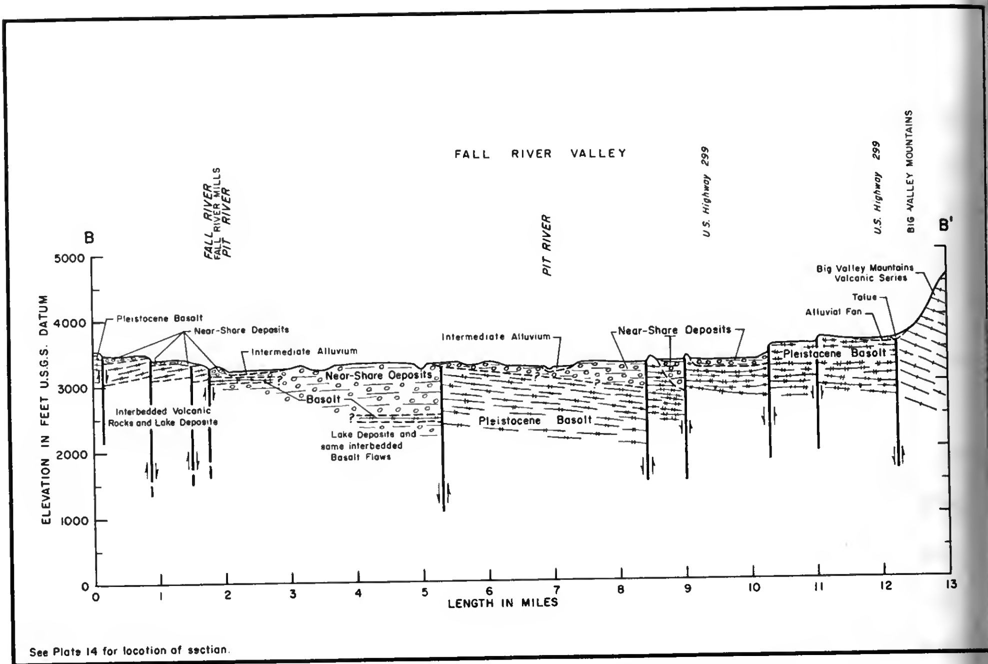


Figure 16. GENERALIZED GEOLOGIC SECTION B-B'
FALL RIVER VALLEY GROUND WATER BASIN

Recharge and Movement of Ground Water

The upland recharge areas, shown on Plate 15, are composed of extremely permeable lavas of Pliocene to Recent age. Precipitation infiltrates these recharge areas and flows valleyward to recharge the aquifers beneath the valley floor area of the ground water basin. Mean seasonal precipitation ranges from a little over 15 inches on the valley floor to about 42 inches at the northwesterly boundary of the drainage area of the valley. In the southwestern portion of the drainage area, precipitation ranges from 16 to 22 inches. Precipitation varies from a minimum of about 10 inches to a maximum of slightly over 30 inches at Fall River Mills. Similar variations can be expected throughout the valley area. The extremely permeable and extensive recharge areas act as ground water storage reservoirs and even out

the variations in supply. Residents state that it takes about five years for the effects of a year of either high or low precipitation to show up in the water supply of the valley.

The ground water basin in Fall River Valley contains both unconfined and confined ground water bodies. The sediments which comprise most of the ground water basin are generally saturated to within a few feet of the ground surface. Available ground water level data indicate that there is a shallow, unconfined ground water body moving toward Fall River from the west and toward Pit River from the north and south. Plate 15 shows two conditions which require explanation. The slight ground water depression located north of Pittville is a local condition probably due to the pumping of several wells located in this area. Whether or not the faults in this area influence the shape or size of this depression is not definitely known. The ground water trough southwest of Glenburn may be due to overpumping during a period of insufficient recharge.

Flowing wells, which indicate the presence of confined aquifers within the bedded lake sediments, are common along the eastern edge of the valley. Some of these confined aquifers may be beds of sand and/or gravel; but for the most part, they consist of highly permeable lava flows which have been buried by valley sediments. Many of the flowing wells in this area have leaky casings or are generally in poor condition, hence piezometric surfaces are often unmeasurable. The slopes of the confined water bodies appear to roughly parallel that of the ground water table. Due to a lack of ground water elevation data, there is a considerable area where the direction of ground water movement is unknown. Long-time residents of the valley report that some 30 years ago, south of McArthur, a steam drill rig encountered sedimentary materials below a lava flow at a depth exceeding 700 feet. This

well, which reportedly flowed, is the only evidence for the existence of ground water at such depths.

Tremendous quantities of ground water, averaging 800 to 1,100 second-feet, are transmitted through the highly permeable Recent basalts north of Fall River Valley and are largely discharged by springs at the headwaters of Fall River. Smaller springs along the east and south edge of the valley are apparently supplied in the same manner. Springs found along the banks of Pit River are the result of the interception of the water table and the ground surface. These springs confirm the direction of ground water movement in near-surface aquifers from upland recharge areas to the springs.

Present Use of Ground Water

The portion of Fall River ground water basin which is overlain by valley floor lands is approximately 53,000 acres, all considered to be irrigable. Because of prior rights to most of the surface water for power development, there is a lack of firm surface water supply and only about 16,000 acres are presently irrigated. Rivers and creeks furnish a major portion of the irrigation water, but a significant amount is pumped from ground water. Information gathered during interviews in 1958 and 1959 indicates that about 1,300 acres were entirely irrigated by ground water. Well drillers reports and field investigations indicate that more and more ground water is being developed each year. Currently, there are about 50 irrigation wells and about 190 domestic and stock wells in Fall River Valley. The wells used for irrigation extract 94 percent of the water pumped.

Irrigation wells in Fall River Valley yield highly variable quantitie of ground water depending primarily upon the depth and ability of underlying aquifers to yield water. Competent construction and development of wells also is important in obtaining high yields. Good irrigation wells yield

1,000 gallons per minute or more, and records show that yields of 2,300 gallons per minute are possible. However, in certain parts of the ground water basin, yields of more than a few gallons per minute are probably unattainable. Ground water storage capacity in the basin is large and conditions of recharge of ground water are excellent. The yield from the less permeable formations is low and fairly high pumping lifts are required to obtain a desired quantity of water.

Ground Water Development Potential

Within the valley floor area of Fall River Valley all four zones of potential for development of ground water are present. The area of the valley floor in each classification is shown on Plate 6. Available ground water data were insufficient to determine the potential for ground water development in certain areas. The general conditions which presently govern the potential for development of ground water within each zone found in this basin are discussed below.

"A" Zone. The potential for ground water development in the "A" Zone areas depends upon the interception by wells of the highly permeable lavas interbedded within the lake sediments. Properly constructed wells of 300 to 400 feet in depth should furnish fairly high yields within these areas. Wells in these areas if supplied primarily from the lake sediments rather than the permeable lavas will require somewhat higher pumping lifts to develop the same yield.

"B" Zone. Available information indicates that most of the irrigable land in Fall River Valley is located within areas classified as "B" Zone. Properly constructed wells several hundred feet in depth should be able to supply most irrigation requirements. These wells will be supplied by ground water contained in the lake and near-shore deposits. If permeable interbedded lavas are encountered, the yield would be considerably increased.

"C" Zone. Restricted irrigation yields from wells located in the "C" Zone areas are possible but should not be expected. The underlying, relatively thin quantities of intermediate alluvium, lake, and near-shore deposits, and the limited opportunity for ground water recharge, restrict the potential yield in these areas.

"D" Zone. The "D" Zone areas have the poorest ground water development potential in Fall River Valley. Wells located in these areas are not expected to produce more than limited domestic or stock supplies. Wells located close to faults or bedrock areas may yield little or no ground water.

General. The combination of excellent recharge opportunity and relatively high precipitation make the overall ground water development potential in Fall River Valley good. A large area in the center of Fall River Valley has not been evaluated as to ground water development potential due to lack of data. It is estimated that this area ranges from "A" Zone potential in the northern part to "C" Zone in the middle and "B" Zone in the southern part.

Ground Water Storage Capacity

The ground water storage capacity to a depth of 400 feet has been estimated to be approximately 1,000,000 acre-feet. How much of this quantity is usable, or how much usable storage exists below 400 feet, is not presently known. It is reasonable, however, to assume that a significant amount of ground water could be developed.

Quality of Ground Water

The ground waters in Fall River Valley are generally excellent in quality and suitable for most beneficial uses. The waters in the central portion of the basin are mostly sodium bicarbonate in character, while those

along the periphery are predominately calcium magnesium bicarbonate. Throughout the western portion of this basin, approximately 30 percent of the wells produce ground waters containing concentrations of iron exceeding that recommended for domestic waters.

Water Quality Problems

The only significant water quality problem which currently exists in Fall River Valley is the high iron content of some of the well waters in the western portion of the basin. These concentrations of iron do not constitute a health problem, but do impair the taste and tend to stain laundry and porcelain fixtures. Although these ground waters are not completely suitable for domestic use, they are suitable for irrigation use.

A few wells scattered throughout the basin yield waters containing nitrate ion concentrations exceeding drinking water standards, and these are not recommended for domestic use. These waters are, however, suitable for irrigation. The nature and distribution of these nitrates indicate that they are the result of localized water quality impairment.

Conclusion

The development of ground water as a source of supplemental supply for irrigation appears promising. Much of the existing and potential use of water in valley floor areas adjacent to the rivers of Fall River Valley is and will be from ground water, as surface water rights are completely obligated. Generally speaking, adequate irrigation yields may be expected from the "A" and "B" Zone areas, shown on Plate 6. The development of additional ground water in sufficient quantities for irrigation use in these zones depends largely on the selection of proper well construction procedure and competent well development practice.

It is concluded that the Department of Water Resources should continue its basic data collection activities in order to facilitate future quantitative and qualitative analyses of the ground water basin. Interested local agencies should be encouraged in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

Sierra, Mohawk, and Humbug Valleys Ground Water Basins

Sierra, Mohawk, and Humbug Valleys are located in Southern Plumas County and Northern Sierra County. The valleys are situated in the upper watershed area of Middle Fork Feather River.

The central portion of Sierra Valley covers an area roughly 12 miles square. Southwesterly of this central portion, there is an arm of the valley which extends southerly over an area roughly 7 miles long and from 4 to 5 miles wide. The average elevation of the floor of Sierra Valley is 4,900 feet. Middle Fork Feather River heads in Sierra Valley and is formed by the confluence of several streams draining the surrounding upland area. Little Last Chance Creek is a major tributary to Middle Fork Feather River. Other tributaries include a network of small streams and channels flowing in a northerly direction through the southern portion of the valley. Middle Fork Feather River flows out of Sierra Valley at its northwestern corner. The river flows through a short gorge into Humbug Valley.

Humbug Valley is about 6 miles long, along a northeast-southwest axis, and about 3 miles wide. The floor of the valley lies at an elevation of about 4,850 feet. To the northwest is Penman Peak, having an elevation of 7,197 feet; to the southeast is Beckwourth Peak, having an elevation of 7,255 feet. Middle Fork Feather River flows southwesterly through the valley. Its major tributaries in this valley are Humbug Creek and Willow Creek. After leaving Humbug Valley, Middle Fork Feather River drops through another canyon into Mohawk Valley.

Mohawk Valley is oriented in a northwest-southeast direction. The valley is roughly 8 miles long and 2 miles wide. Its floor lies at an elevation of about 4,500 feet. Penman Peak is to the north and Beckwourth Peak is to the east, while the main crest of the Sierra Nevada is to the west. This

crest rises to 7,812 feet at Mt. Elwell and 8,107 feet at Haskell Peak. Middle Fork Feather River enters Mohawk Valley near the mid-point of its northeastern side. It then joins Sulphur Creek, turns northwesterly, and leaves the valley by way of a canyon at its lower end. Other tributaries to Middle Fork Feather River include Frazier Creek, Gray Eagle Creek, and Smith Creek.

Surface exposures of the various geologic formations of the Sierra, Mohawk, and Humbug Valleys region are shown on Plate 17, Areal Geology, Sierra, Mohawk, and Humbug Valleys Ground Water Basins. Plate 18, Generalized Lines of Equal Elevation of Water in Wells in Near-Surface Aquifers, Sierra, Mohawk, and Humbug Valleys Ground Water Basins, Spring 1960, is a generalized picture of the elevation of unconfined or semiconfined ground water within the ground water basins. Plate 19, Generalized Lines of Equal Elevation of Water in Wells in Confined Aquifers, Sierra, Mohawk, and Humbug Valleys Ground Water Basins, Spring 1960, indicates the general elevation to which confined ground water would rise in a well. Plate 20, Potential for Development of Ground Water, Sierra, Mohawk, and Humbug Valleys Ground Water Basins, presents the preliminary evaluations of the potential for ground water development within these basins. Areas of hazard because of poor quality water are also indicated on Plate 20.

Geologic History

The Tertiary history of the Sierra, Mohawk, and Humbug Valley area is one of widespread volcanism. Up until the middle of the Pliocene epoch, the region was the site of outpourings of andesite, ash, tuff breccia, and basalt. Associated with this volcanic activity was a period of extensive faulting which formed Sierra, Mohawk, and Humbug Valleys. After the valleys had formed, they became the location of lakes..

During the great ice ages of the Pleistocene epoch, glaciers mantled the Sierra Nevada. In moving down the mountain sides, they quarried and polished the bedrock and deposited the rock debris as moraines. At the same time, Pleistocene lakes received sediments from the surrounding mountains and outwash debris from the melting glaciers. The lakes drained westward into Jamison Creek and thence into Middle Fork Feather River. Eventually, a new outlet to the lakes was formed directly into Middle Fork Feather River. This new outlet was slowly eroded downward until both lakes were completely drained, leaving the valleys much as they are today.

Water-Bearing Formations

Table 13 briefly describes the geologic formations in Sierra, Mohawk, and Humbug Valleys. Of these, the principal water-bearing formations are Pleistocene lava flows, glacial outwash, lake and near-shore deposits, and Recent valley sediments.

Pleistocene Lava Flows. A mass of Pleistocene basalt is located south of the town of Vinton. Here, lava flowed out onto the valley floor and also covered the surrounding hills. After eruptions had ceased, the volcanic vent became plugged with lava. Subsequent erosion has stripped off large quantities of material, exposing the plugged vent as a volcanic neck. This neck can be seen today and is located several miles south of Vinton.

The Pleistocene basalt acts as a recharge area to ground water on the east side of Sierra Valley. A few wells intercept these lava flows where they have become buried in lake deposits. Because these lava flows are more permeable than the enclosing lake deposits, the lavas yield large amounts of confined water to the wells.

GEOLOGIC FORMATIONS IN SIERRA, MOHAWK, AND HUMBUG VALLEYS

GEOLOGIC AGE	GEOLOGIC FORMATION	STRATIGRAPHY	APPROXIMATE THICKNESS IN FEET	PHYSICAL CHARACTERISTICS	WATER-BEARING CHARACTERISTICS
CENOZOIC — QUATERNARY — RECENT	SAND DEPOSITS	Qs	0-25	Qs: Loose, wind-blown sand.	Highly permeable but located above water table, hence contain little water.
CENOZOIC — QUATERNARY — RECENT	BASIN DEPOSITS	Qb	0-50	Qb: Unconsolidated silt and clay; may contain some alkali.	Low permeability; may yield small amounts of water to domestic wells.
CENOZOIC — QUATERNARY — RECENT	INTERMEDIATE ALLUVIUM	Qal	0-50	Qal: Unconsolidated sand and silt with lenses of clay and gravel.	Moderate permeability. Yields moderate quantities of water to wells.
CENOZOIC — QUATERNARY — RECENT	ALLUVIAL FANS	Qf	0-200	Qf: Unconsolidated gravel, sand, and silt with clay lenses.	Moderate to high permeability. Yields large amounts of water to wells. May contain confined water.
CENOZOIC — QUATERNARY — PLEISTOCENE	TERRACES	Qt	0-25	Qt: Unconsolidated gravel, sand, silt, and clay.	Moderate permeability. Yields moderate amounts of water to shallow wells.
CENOZOIC — QUATERNARY — PLEISTOCENE	NEAR-SHORE DEPOSITS	Qps	0-250	Qps: Slightly consolidated, bedded gravel, sand, and silt.	Moderately permeable. Yields moderate quantities of water to wells. Contains confined water.
CENOZOIC — QUATERNARY — PLEISTOCENE	LAKE DEPOSITS	Qpl	0-2000	Qpl: Slightly consolidated, bedded sand, silt, and diatomaceous clay.	Moderately to highly permeable. Principal aquifer in valleys. Yields moderate to large quantities of water to wells. Contains confined water.
CENOZOIC — QUATERNARY — PLEISTOCENE	PLEISTOCENE BASALT	Qpvb	50-300	Qpvb: Jointed basalt flows containing zones of scoria.	Moderate to high permeability. May yield large quantities of water to wells. May contain confined water.
CENOZOIC — QUATERNARY — PLEISTOCENE	GLACIAL OUTWASH	Qpo	0-100	Qpo: Poorly consolidated mixture of gravel and silt.	Moderate permeability. May locally yield moderate quantities of water to wells.
CENOZOIC — QUATERNARY — PLEISTOCENE	MORAINES	Qpm	0-700	Qpm: Slightly consolidated mixture of boulders, cobbles, sand, and rock flour.	Low permeability. A few areas may yield small amounts of water.
CENOZOIC — TERTIARY — PLIOCENE	PLIOCENE LAKE DEPOSITS	Tpl	0-3000?	Tpl: Bedded, consolidated sandstone and siltstone. Occurs only in Long Valley.	Low to moderate permeability. May yield moderate quantities of water to wells. May contain confined water.
CENOZOIC — TERTIARY — PLIOCENE	RHYOLITE	Tvr	?	Tvr: Jointed, light gray rhyolite.	Essentially impermeable.
CENOZOIC — TERTIARY — PRE-PLIOCENE	SIERRAN VOLCANIC ROCKS — BASALT	Tsvb	4000	Tsvb, Tsva, Tsvp, Tsv: Flows of fractured basalt. Plugs and flows of massive to platy andesite. Massive to bedded mudflows and tuffs.	Permeability ranges from poor to moderate. Basalt may be permeable, but is mostly located above zone of saturation and hence is unimportant to ground water. Andesite and pyroclastic rocks are essentially impermeable.
CENOZOIC — TERTIARY — PRE-PLIOCENE	SIERRAN VOLCANIC ROCKS — ANDESITE	Tsvo, Tsv			
CENOZOIC — TERTIARY — PRE-PLIOCENE	SIERRAN VOLCANIC ROCKS — PYROCLASTIC ROCKS	Tsvp			
MESOZOIC — JURASSIC TO CRETACEOUS	BASEMENT COMPLEX — GRANITIC ROCKS	JKgr	?	JKgr: Hard, nonweathered granitic rocks.	Essentially impermeable.
PRE-CRETACEOUS	BASEMENT COMPLEX — METAMORPHIC ROCKS	pKm	?	pKm: Massive quartzite, slate, limestone, and meta-volcanic rocks.	Essentially impermeable.

Glacial Outwash. Glacial outwash deposits occur mostly along the west side of Mohawk Valley. The deposits are moderately permeable and may yield moderate amounts of ground water to wells. There are several permeable zones in the glacial outwash deposits which yield notable quantities of ground water to springs.

Lake and Near-Shore Deposits. The central portions of Sierra, Mohawk, and Humbug Valleys are largely made up of lake and near-shore deposits which are overlain by Recent sediments. The lake and near-shore deposits are up to 2,000 feet thick and provide most of the ground water developed in the valleys. The lake deposits range in composition from permeable sand to nearly impermeable clay. The sand beds usually yield large quantities of confined ground water to wells. The near-shore deposits are composed of moderately permeable sand and gravel and where saturated usually yield moderate amounts of ground water to wells.

Recent Valley Sediments. The Recent valley sediments include alluvial fans, intermediate alluvium, and basin deposits. Although Recent sand and silt deposits and Pleistocene to Recent terraces are actually a part of the valley sediments, they are not discussed because of their limited areal extent and limited use as a source of ground water.

Alluvial fans surround most of Sierra Valley. The fans may be as much as 200 feet thick and are a major source of ground water in the valley. Where adequately recharged they should be able to provide large quantities of both confined and unconfined ground water to wells.

There are a few areas of intermediate alluvium in Sierra, Mohawk, and Humbug Valleys. These deposits are estimated to be not over 50 feet thick and are underlain by lake deposits. The intermediate alluvium provides fair to good quantities of ground water to shallow wells.

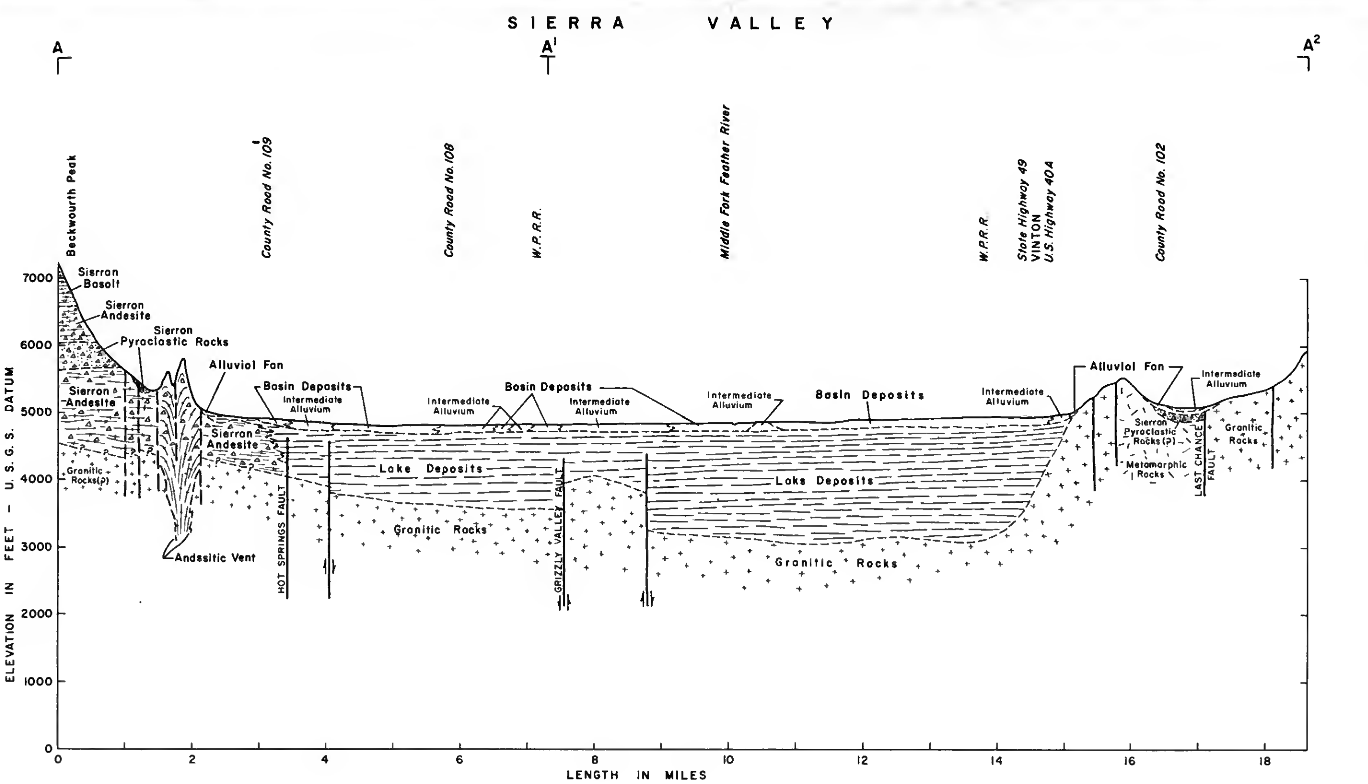
Basin deposits occur only in the central, poorly drained portion of Sierra Valley. These deposits are estimated to have a thickness of about 50 feet and are underlain by lake deposits. The basin deposits are of low permeability and generally yield only small amounts of water to shallow wells; however, the presence of alkali may adversely affect the quality of the water.

Influence of Geologic Structure on Ground Water

The mountains surrounding Sierra, Mohawk, and Humbug Valleys contain numerous faults, many of which are shown on Plate 17. A recent geophysical survey of Sierra Valley by the Department of Water Resources indicated that faults have broken the bedrock beneath the valley floor into numerous tilted fault blocks. This has resulted in a bedrock surface which ranges from a few hundred feet to about 2,000 feet below the floor of the valley. An idea of the geologic structure of Sierra Valley can be seen in generalized geologic sections $A-A^1-A^2$ and $B-B^1-B^2$, presented on Figures 17 and 18, respectively. These sections show the probable structural conditions to a depth of about 2,500 feet below the floor of the valley, largely from interpretation of the geophysical survey by the department.

The survey indicates that the bedrock beneath the floor of Sierra Valley has been broken into several high and low areas, bounded by the faults which enter the valley from the north and south. The thickness of sediments overlying the high areas is about 800 to 1,000 feet while that overlying the low areas is on the order of 2,000 feet.

The origin and history of the low volcanic hills knows as The Mounds are somewhat uncertain. These hills apparently do not have a bedrock connection and thus may be resting on lake sediments, as shown on Figure 18. They apparently were formed by a tongue-like mass of andesite lava which flowed out into the valley and then became almost completely buried by later



See Plate 17 for location of section.

Figure 17. GENERALIZED GEOLOGIC SECTION A-A'-A²
SIERRA VALLEY GROUND WATER BASIN

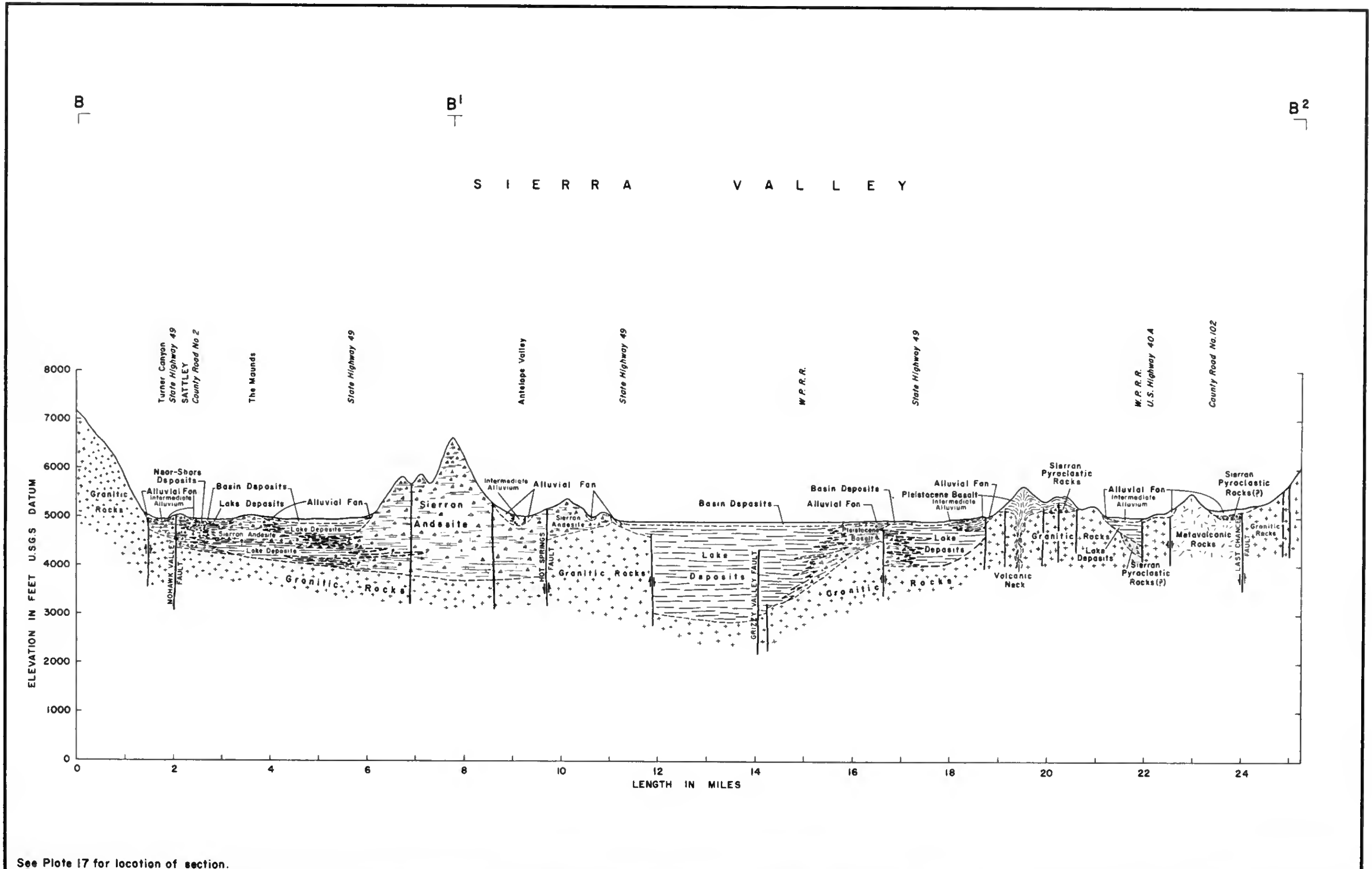


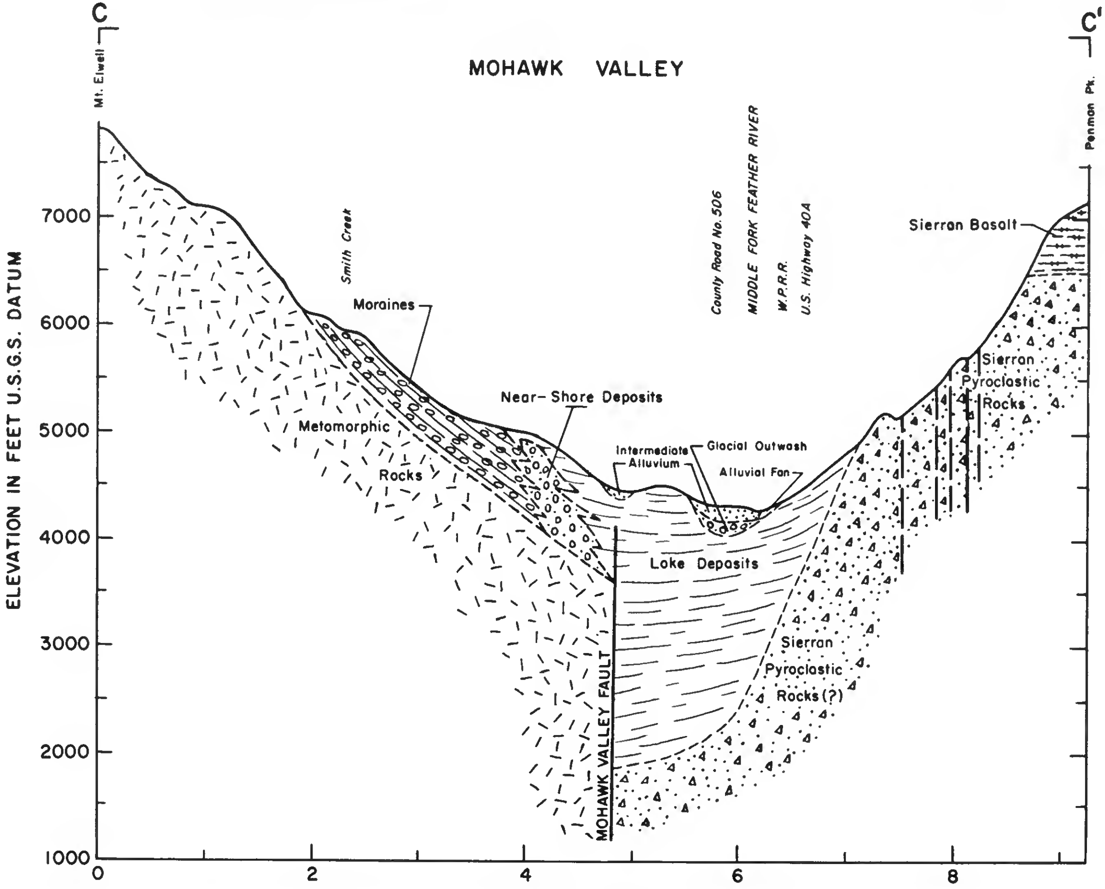
Figure 18. GENERALIZED GEOLOGIC SECTION B-B¹-B²
SIERRA VALLEY GROUND WATER BASIN

sedimentation. In contrast, The Buttes are made up of andesite and granitic bedrock surrounded, but not underlain, by lake deposits.

Many of the faults shown on Plate 17 have very little, if any, effect on ground water movement or quality. Faults cutting through the mountainous areas are in this category. Other faults, particularly those in the Pleistocene basalt near Vinton, could serve as vertical passages for the movement of precipitation downward to the ground water body. Some of the faults passing beneath the valley floor serve as passageways for the upward percolation of deep-seated thermal water. This water rising along faults mixes with deep percolating ground water and comes to the surface at Campbell Hot Springs, Marble Hot Springs, and at the numerous hot artesian wells found in Sierra Valley.

Mohawk Valley is bounded by two major fault zones, the Mohawk Valley fault, running along the southwest side of the valley, and unnamed faults running along the northeast side. Mohawk Valley has been downdropped along the faults on each side. The bedrock floor of the valley is broken by several faults crossing it at nearly right angles, creating an irregular, tilted bedrock surface. This bedrock surface is now covered by from 1,500 to 3,000 feet of lake deposits. Generalized geologic section C-C^1, presented on Figure 19, diagramatically shows conditions beneath a portion of the floor of Mohawk Valley.

Similar to conditions in Sierra Valley, most of the faults in Mohawk Valley shown on Plate 17 have very little effect on ground water movement or quality. However, the Mohawk Valley fault and the east side faults may serve as permeable paths for the upward migration of hot, deep-seated water. That this is the case is illustrated by the hot springs at McLears Resort.



See Plate 17 for location of section.

Figure 19. GENERALIZED GEOLOGIC SECTION C-C'
MOHAWK VALLEY GROUND WATER BASIN

Very little is known of the structure of Humbug Valley. It appears to be faulted in a similar manner as Mohawk Valley. The depth to bedrock in Humbug Valley is probably not over 500 feet.

Recharge and Movement of Ground Water

The recharge and movement of ground water were evaluated for only Sierra and Mohawk Valley ground water basins. Insufficient data were available to make such an evaluation for Humbug Valley.

Sierra Valley Ground Water Basin. Most of the upland recharge areas in Sierra Valley ground water basin, shown on Plates 18 and 19, are composed of permeable materials occurring along the upper portions of the alluvial fans which border the valley. Recharge to ground water is primarily by way of infiltration of surface water from the streams which drain the mountains and flow across these fans. A minor amount of recharge also may be derived from some of the Sierran volcanic rocks which surround much of the valley. Most of these rocks appear to be of fairly low permeability and thus only small quantities of recharge could be derived from them.

Mean seasonal precipitation varies from about 12 inches on the valley floor to more than 40 inches on the upper portion of the drainage area. The maximum and minimum seasonal precipitation at Sierraville was respectively 43.80 inches during the 1912-13 season and 8.23 inches during the 1923-24 season. The mean seasonal precipitation is 24.23 inches. At Portola, the mean seasonal precipitation is 18.14 inches. The maximum and minimum recorded seasonal values are 36.10 inches during the 1951-52 season and 6.17 inches during the 1923-24 season, respectively.

An essentially unconfined ground water body underlies the valley floor area of Sierra Valley at shallow depths. Lines of equal elevation of this ground water body are shown on Plate 18. Wells which intercept this body are usually less than 100 feet in depth and are used primarily for domestic purposes. Water surface levels from wells supplied by this near-surface source indicate that the direction of movement of this ground water body is similar to the general direction of surface water movement in the valley.

A large quantity of ground water which underlies the floor of Sierra Valley is contained within numerous confined aquifers. Wells which intercept these aquifers usually flow. Depths of flowing wells range from about 100 feet along the margin of the valley floor to as much as 1,000 feet in the central part of the valley. Plate 19 shows lines of equal elevation of this confined ground water body. The piezometric surface of this ground water body slopes generally toward the northwest. The portion of the valley floor within which wells flow is also shown on Plate 19. This particular area may extend to the base of the foothills in the vicinity of Sierraville. The ground water mound in the vicinity of Marble Hot Springs is apparently due to thermal waters which rise along fracture zones of the Hot Spring fault and the intersecting fault to the east. The area of influence of Marble Hot Springs is believed to be fairly limited. Water from wells in the vicinity of the hot springs ranges in temperature up to 206° Fahrenheit and is generally of poor quality. Undoubtedly, some of the thermal waters commingle with ground water from confined aquifers in the vicinity of the fault zones. To reiterate, at least three different types of ground water may be intercepted by wells drilled in Sierra Valley, a near-surface unconfined body, a deeper confined body, and deep seated thermal waters in the vicinity of faulting.

Mohawk Valley Ground Water Basin. Despite the fact that the upland recharge area for Mohawk Valley ground water basin is considerably greater than that for Sierra Valley, the upland deposits are at best only moderately permeable. Pyroclastic rocks which adjoin the valley on the northeast are essentially impermeable except along bedding planes, joints, and fractures. Morainal deposits along the southwest border have a high clay content and are only locally permeable.

Mean seasonal precipitation varies from about 28 inches on the valley floor to over 50 inches on some of the higher peaks to the southwest of the valley. There are no precipitation stations with long term records in Mohawk Valley.

Ground water data are extremely scarce in Mohawk Valley, hence the lines of equal elevation shown on Plate 18 are based primarily on topography, the location and flow of springs, and other observable factors. Ground water is believed to move toward Sulphur Creek and Middle Fork Feather River from the northeastern and southwestern sides of the valley. Both unconfined and confined ground water bodies exist in the valley but insufficient data are available to define them at this time. Most of the ground water level measurements in wells probably reflect a combination of both confined and unconfined ground water.

The many small springs which are found in and around Mohawk Valley are due principally to local permeable zones in the morainal deposits. The warm sulphur springs at McLear's Resort are apparently due to water rising along a fault.

Present Use of Ground Water

The majority of the 42,000 acres of irrigated lands within Sierra Valley are situated adjacent to the surface streams. The flows from these

streams are primarily from snowmelt and are insufficient to irrigate the 106,000 acres of irrigable lands within the floor of Sierra Valley. Supplemental irrigation water is usually required after the first of June within the northern portion of the valley floor. The southeastern portion and western portions of the valley floor usually need supplemental water after the middle of June and the first of July, respectively. Recently constructed Frenchman Dam and Reservoir on Little Last Chance Creek will provide additional water supplies to the northeastern portion of the valley floor. The yield from existing and potential surface water developments is insufficient to irrigate all of the irrigable lands within the valley floor.

The use of ground water for irrigation purposes has increased in recent years, although only 13 of the 405 wells inventoried during the period of investigation were used for irrigation purposes, while the majority were used for domestic and stockwater purposes. Two wells near Loyalton served as a partial municipal supply for this community.

The reported ground water yields of the irrigation wells inventoried range from about 600 to 1,800 gallons per minute. The maximum reported non-pumped flowing well yield is 300 gallons per minute.

The portion of Mohawk Valley ground water basin classified as valley floor land encompasses about 10,000 acres, over half of which is irrigable. About 2,000 acres are presently irrigated and the water supply is obtained by diversions from streams within the area. Only six wells have been located in Mohawk Valley and none of them is classified as an irrigation well.

Ground Water Development Potential

All four zones of potential for development of ground water are present in Sierra Valley. Only three of the zones are present in Mohawk

Valley. Humbug Valley ground water basin was not evaluated. The area of the valley floors in each classification is shown on Plate 20. The general conditions which presently govern the potential for development of ground water within each zone found in the two valleys are discussed below.

<u>Sierra Valley "A" Zone.</u> "A" Zone areas, located near Loyalton and Sierraville, are apparently underlain by thick alluvial fan and near-shore deposits. Adequate recharge of ground water within these areas is by way of infiltration of surface water into the relatively extensive alluvial fan deposits located south of the two areas.

<u>Sierra Valley "B" Zone.</u> The "B" Zone areas in Sierra Valley are underlain by near-shore, alluvial fan, and other sediments which are similar to those in the "A" Zone areas, but are either less permeable, thinner, or possess less ground water recharge potential. As a result, the ground water development potential of the "B" Zone areas is less than that of the "A" Zone areas.

Part of the northern portion of the eastern "B" Zone area is underlain by basalt flows interbedded with lake deposits. If these basalt flows are adequately recharged and sufficiently permeable, a relatively higher yield can be expected from this portion of the eastern "B" Zone area.

<u>Sierra Valley "C" Zone.</u> Within "C" Zone areas the probability of constructing high yield irrigation wells does not appear favorable, but well yields should generally be sufficient for domestic and stock-watering uses. The valley fill sediments near the edge of the valley floor are composed essentially of the thinner portions of alluvial fans overlain by a relatively thin mantle of intermediate alluvium and basin deposits. Within the west central portion of the valley, the valley fill sediments consist primarily of

lake deposits overlain by a thin mantle of basin deposits. The relatively shallow thickness of the sedimentary materials near the edge of the valley floor, and the relatively low permability of the sedimentary materials within the west central portion of the valley, restrict the ground water development potential of these areas. The "C" Zone area southwest of Vinton may possess a higher development potential than indicated if underlying basalt flows prove to be reliable aquifers.

Sierra Valley "D" Zone. "D" Zone areas are located adjacent to impermeable rock or within areas possessing particularly low recharge potential. The sedimentary materials within these zones are permeable, but their thinness and low recharge limit well yields to relatively small quantities.

General. High yielding irrigation wells may be located within two portions of the floor of Sierra Valley. One such area is situated near the southern end of the Sierraville arm of the valley floor, and the other is northwesterly from Loyalton. Underlying this latter area are buried basalt flows which may yield large quantities of ground water to wells approximately 1,000 feet deep. Below the point where the major streams enter the valley floor, there are areas within which irrigation wells of moderate yield may be located. Most of the remainder of the valley floor area does not appear to be suitable for irrigation well development. Wells for domestic and stock-watering uses may be located almost anywhere on the valley floor except within areas underlain at shallow depths by impermeable rock.

Mohawk Valley "B" Zone. The area of Mohawk Valley which is classifi as "B" Zone is located southeasterly of Graeagle. The sands and gravels which underlie this area are permeable and are recharged from Middle Fork Feather River and other streams. Wells capable of producing supplies of ground water

sufficient for irrigation purposes are possible, providing proper well construction and competent development practices are followed.

Mohawk Valley "C" Zone. Most of Mohawk Valley is classified as a "C" Zone area. Wells located here have only a fair development potential because of the fairly low permeability of the underlying materials. Occasional irrigation yields may be obtained, but should not be expected.

Mohawk Valley "D" Zone. Materials underlying the "D" Zone areas range from permeable alluvial fan deposits through poorly permeable glacial outwash deposits. "D" Zone areas in Mohawk Valley are so classified principally because the water-bearing materials are thin. Wells in "D" Zone areas would yield little, if any, ground water.

Ground Water Storage Capacity

The ground water storage capacity of Sierra Valley has been estimated to be about 7,500,000 acre-feet for the depth interval between zero and 1,000 feet. Storage capacity for Mohawk Valley has been estimated to be about 90,000 acre-feet for the depth interval zero to 200 feet, and that for Humbug Valley has been estimated to be about 76,000 acre-feet for the depth interval zero to 100 feet. How much of the ground water in storage is useable or how much useable storage exists below the depth intervals cited is not known. It is reasonable to assume that a significant amount of ground water could be developed.

Quality of Ground Water

Ground waters in Sierra Valley display a wide range in mineral quality. The ground waters in this valley south of Highway 40A and north and west of Loyalton are usually poor in quality. Within this area there are hot springs and thermal artesian wells associated with faults as previously

described. The poorest of the thermal waters are mostly sodium chloride in character and are considered hazardous for most beneficial uses, while the remainder of the waters are mostly sodium bicarbonate. Ground waters elsewhere in the valley are of good quality and suitable for most beneficial uses. No particular cation is dominant in these waters but bicarbonate is usually the predominant anion.

The ground waters in Mohawk Valley are generally of excellent mineral quality. They range in character from calcium-magnesium bicarbonate to sodium bicarbonate and are suitable for most beneficial uses.

Water Quality Problems

The hot springs and several of the thermal artesian wells in Sierra Valley yield waters which are considered hazardous due to high electrical conductivity and excessive concentrations of boron, chloride, fluoride, iron, and sodium. Several wells also yield water containing significant concentrati[ons] of arsenic and manganese. All of these waters, which are unsuitable for most beneficial uses, are located within the hazard area shown on Plate 20. Water quality data indicate that mineralized waters have migrated from the hot springs and thermal artesian wells and impaired adjacent ground water within this area. Although waters of usable quality can be found within this area, more often waters of hazardous quality will be found. Excessive boron has been found in the waters throughout this entire area.

Scattered throughout Sierra Valley are a few other wells yielding ground waters which contain excessive concentrations of one or more of the following constituents: fluoride, iron, manganese, and nitrate. However, these appear to be only localized conditions of impairment.

Conclusion

Within Sierra Valley, moderate to high yielding irrigation wells can apparently be developed within about one quarter of the valley floor area.

Within a portion of this area, wells are subject to pumping water which is of poor quality for irrigation. Well yields within the remaining three-quarters of the valley floor area are restricted principally by low aquifer permeability. One possible exception is the buried basalt flows along a portion of the eastern side of the valley floor. These flows may prove to be reliable aquifers. Upland areas of recharge are very limited surrounding Sierra Valley.

Water quality will also limit ground water development within the northwestern portion of the valley floor area. If a high level of ground water development is achieved along the eastern side of the valley floor, the area of water quality hazard probably will migrate eastward.

The ground water development potential of Mohawk Valley for irrigation purposes is generally limited by the low permeability of materials underlying much of the valley floor. Generally, the quality of ground water within the Mohawk Valley ground water basin is excellent.

Except for the water quality hazard within Sierra Valley, ground water development potential for domestic and stockwatering uses appears good throughout both Sierra and Mohawk Valleys.

It is concluded that the basic data collection activities of the Department of Water Resources should be continued in order to facilitate future quantitative and qualitative analyses of the ground water basin. Encouragement should be offered to local agencies in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

Surprise Valley Ground Water Basin

Surprise Valley ground water basin is located in eastern Modoc County and northeastern Lassen County, California, and western Washoe County, Nevada. The valley is roughly 50 miles long and 12 miles wide. Its floor lies at an elevation of about 4,500 feet. The valley is bounded on the west by the Warner Mountains, which rise to an elevation of 9,883 feet at Eagle Peak. To the east, in Nevada, is the Hays Canyon Range, having a maximum elevation of over 7,000 feet. Surprise Valley is one of internal drainage as it has no outlet. The valley contains three lakes, Upper Alkali Lake, Middle Alkali Lake, and Lower Alkali Lake. The lakes are shallow, extremely saline, and are usually dry during the summer months. Most of the streams draining into Surprise Valley originate along the eastern slopes of the Warner Mountains and discharge into the three lakes.

Surface exposures of the various geologic formations of the Surprise Valley area are shown on Plate 21, Areal Geology, Surprise Valley Ground Water Basin. Plate 22, Generalized Lines of Equal Elevation of Water in Wells in Aquifers, Surprise Valley Ground Water Basin, Spring 1960, is a generalized picture of the elevation of ground water within the ground water basin. Plate 23, Potential for Development of Ground Water, Surprise Valley Ground Water Basin, presents the preliminary evaluations of the potential for ground water development within this basin. Areas of hazard because of poor quality water are also indicated on Plate 23.

Geologic History

During the early part of the Tertiary period, the area which now includes Surprise Valley was a land of low, rolling hills and extensive lava plains. Late Miocene faulting broke the old land surface and formed an

entirely new landscape consisting of fault block mountains and long, narrow valleys, one of which is now Surprise Valley.

During the Pleistocene epoch, there was a decrease in the temperature and a corresponding increase in the precipitation. Because the valley had no outlet, a lake formed. This lake, called Lake Surprise, slowly grew in size until by about 70,000 years ago, it had attained a depth of about 500 feet. The lake persisted for about 15,000 years until a decrease in precipitation and a general warming of the region caused the lake nearly to dry up. Then there was reversal of the warming trend, colder and wetter years again predominated, and once more the lake filled the valley. The second lake lasted until about 20,000 years ago. The many old beaches and terraces seen along the sides of the valley today near elevation 5,000 feet offer mute evidence of the size and depth of this once great lake.

During much of the time that Lake Surprise was present, glaciers mantled the Warner Mountains. These ice masses carved great cirques into the mountain crest. The end of the glacial period was marked by a gradual increase of temperatures and a decrease in precipitation. The glaciers were the first to disappear. Then the lake itself slowly began to shrink in size and depth. Today, the three alkali lakes remain as mere remnants of ancient Lake Surprise.

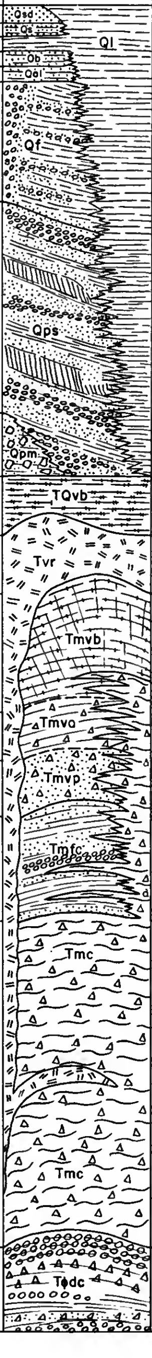
Water-Bearing Formations

Table 14 briefly describes the geologic formations in Surprise Valley. Of these, the principal water-bearing formations are near-shore deposits and Recent valley sediments.

Near-Shore Deposits. Near-shore deposits occur as highly permeable terraces, beaches, spits, and deltas formed in ancient Lake Surprise. Where

TABLE 14

GEOLOGIC FORMATIONS IN SURPRISE VALLEY

EOLOGIC AGE		GEOLOGIC FORMATION	STRATIGRAPHY	APPROXIMATE THICKNESS IN FEET	PHYSICAL CHARACTERISTICS	WATER-BEARING CHARACTERISTICS
QUATERNARY	RECENT	SAND DUNES	 Qsd	0-30	Qsd: Unconsolidated, wind-blown sand.	Highly permeable. Located above water table; acts to recharge underlying materials. Yields little water.
QUATERNARY	RECENT	SAND & SILT DEPOSITS	Qs	0-20	Qs: Unconsolidated, wind-blown sand and silt; alkali often present.	Permeable but contains little water due to being above water table.
QUATERNARY	RECENT	LAKE DEPOSITS	Ql	0-5000	Ql: Unconsolidated to semi-consolidated clay, organic muck, and fine sand. Alkali and salt present.	Generally nearly impermeable. Contains small amounts of confined water in stringers of fine sand.
QUATERNARY	RECENT	BASIN DEPOSITS	Qb	0-50	Qb: Unconsolidated deposits of sand, silt, clay, and organic muck.	Permeability generally low, but locally may be sufficiently permeable to yield small amounts of water to shallow wells.
QUATERNARY	RECENT	INTERMEDIATE ALLUVIUM	Qal	0-50	Qal: Unconsolidated sand and silt with some gravel and clay lenses.	Moderately permeable; yields moderate amounts of water to wells.
QUATERNARY	RECENT	ALLUVIAL FANS	Qf	0-1000	Qf: Unconsolidated to partly consolidated, poorly stratified gravel, sand, and silt with clay lenses.	Generally highly permeable. Important west side aquifer; yields abundant supplies of free and confined water.
QUATERNARY	PLEISTOCENE	NEAR-SHORE DEPOSITS	Qps	0-5000	Qps: Poorly consolidated gravel, sand, and silt deposited as deltas and terraces.	Moderate to high permeability. Yields large quantities of free and confined water.
QUATERNARY	PLEISTOCENE	MORAINES	Qpm	0-200(?)	Qpm: Unconsolidated mixture of boulders, gravel, silt, clay, and rock flour.	Low permeability. May yield minor amounts of water to springs.
QUATERNARY	PLEISTOCENE	PLIO-PLEISTOCENE BASALT	TQvb	0-300	TQvb: Highly jointed vesicular basalt flows.	Permeability ranges from low to high. Acts to recharge sediments in Surprise Valley. May yield moderate amounts of water to wells.
TERTIARY	MIOCENE THROUGH PLIOCENE	RHYOLITE	Tvr	?	Tvr: Fractured flows and shallow intrusives of pale-colored rhyolite.	Essentially impermeable.
TERTIARY	MIOCENE	MIOCENE VOLCANIC ROCKS: BASALT	Tmvb	1500	Tmvb, Tmva, Tmvp: Jointed vesicular basalt flows, flows of platy andesite, and beds of rhyolite tuff.	Permeability ranges from poor to moderate. Basalt acts as recharge area. May locally yield moderate amounts of water to wells. Andesite and pyroclastic rocks are essentially impermeable.
TERTIARY	MIOCENE	MIOCENE VOLCANIC ROCKS: ANDESITE	Tmva			
TERTIARY	MIOCENE	MIOCENE VOLCANIC ROCKS: PYROCLASTIC ROCKS	Tmvp			
TERTIARY	MIOCENE	FORTY-NINE CAMP FORMATION	Tmfc	750 ?	Tmfc: Consolidated tuffaceous sand and volcanic gravel.	Moderate permeability. Certain beds may yield moderate amounts of water to wells.
TERTIARY	MIOCENE	CEDARVILLE SERIES	Tmc	7500	Tmc: Massive tuff-breccias and tuffs. Includes flows of Miocene basalt and andesite. Also includes some tuffaceous sediments correlative with Forty-nine Camp formation.	Essentially impermeable.
TERTIARY	OLIGOCENE	DEEP CREEK CONGLOMERATE	Tϕdc	?	Tϕdc: Massive, consolidated conglomerate with beds of shale, mudflows, and tuff.	Essentially impermeable.

these deposits are exposed on the ground surface, they are important as recharge areas. Where below ground and saturated, they are important water-bearing materials as they are capable of yielding large amounts of ground water to wells.

Recent Valley Sediments. Recent valley sediments include alluvial fans, intermediate alluvium, and basin deposits. Although the lake deposits in the three alkali lakes are actually a part of the Recent valley sediments, they are not discussed below because they yield only small amounts of ground water.

Alluvial fans in Surprise Valley may be as much as 1,000 feet in thickness and contain the principal aquifers in the valley. These aquifers are capable of yielding large quantities of confined and semiconfined ground water to wells. The alluvial fans also are important as recharge areas, particularly the highly permeable upper portions of fans along the west side of Surprise Valley.

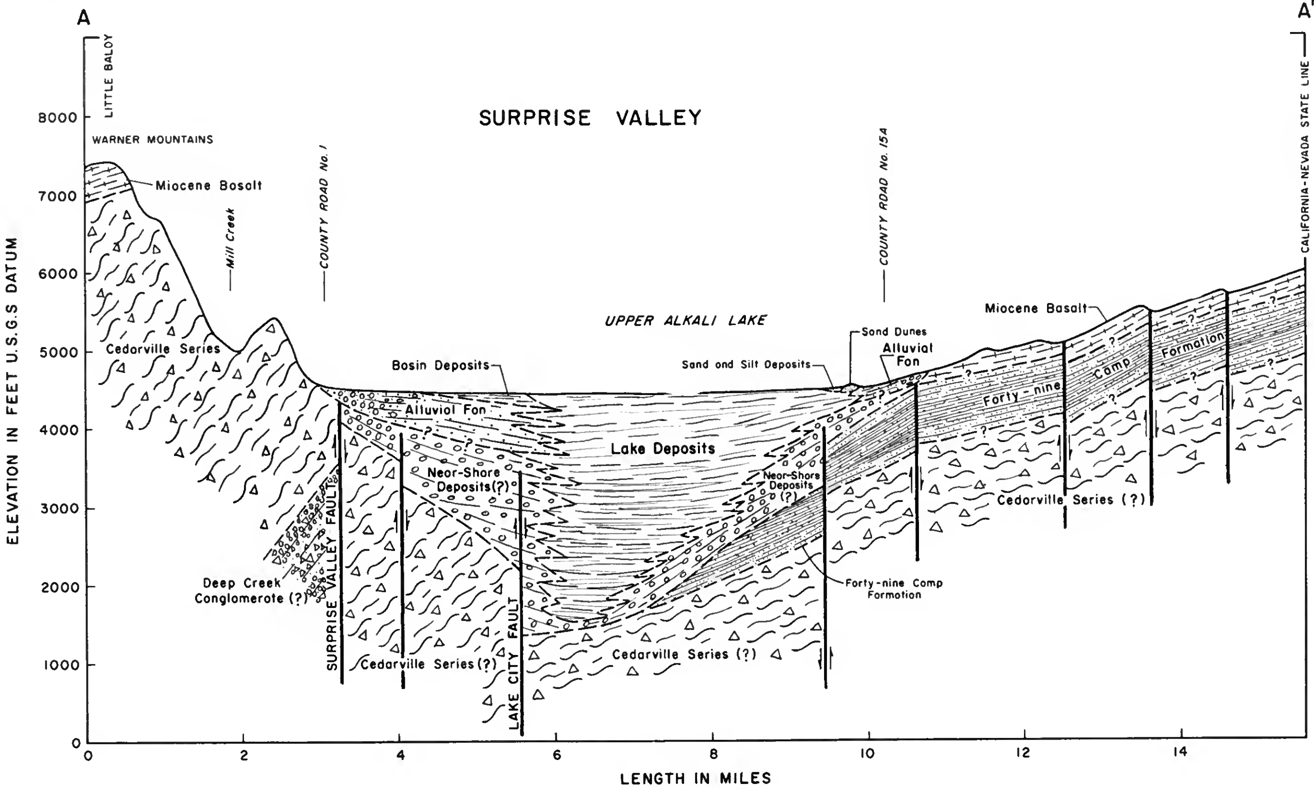
Intermediate alluvium occurs between the alluvial fans and the basin deposits. These intermediate alluvial deposits are estimated to be not over 50 feet in thickness. They are underlain in some places by the valleyward extensions of the alluvial fan deposits, and in other places by lake deposits. In general, the intermediate alluvium is only moderately permeable, and will yield moderate amounts of ground water to shallow wells.

Basin deposits occur in the flat portion of the valley along the western edges of the alkali lakes. These deposits are estimated to be not over 50 feet thick. In some places they are underlain by the valleyward extension of alluvial fan deposits, and elsewhere by lake deposits. The permeability of the basin deposits is generally low, but locally they may be sufficiently permeable to yield small amounts of water to shallow wells.

Influence of Geologic Structure on Ground Water

Surprise Valley is an elongated, faulted depression bounded by uplifted, tilted mountain ranges. The valley and its surrounding mountains are crossed by numerous faults, many of which are shown on Plate 21. Many of these faults are clearly visible in the upland regions, but faults passing beneath the floor of the valley are hidden from view. In order to determine the location of these hidden faults, it was necessary to make a geophysical survey of the valley floor area. The survey showed that the bedrock beneath the valley floor has been broken into many tilted fault blocks, resulting in a bedrock surface which ranges from a few hundred feet to over 5,000 feet below the floor of the valley. An idea of the geologic structure of the valley can be had by referring to generalized geologic sections $A\text{-}A^1$ and $B\text{-}B^1$ presented on Figures 20 and 21, respectively. These sections show the probable structural conditions to a depth of about 5,000 feet below the floor of the valley. Subsurface features shown on these figures, as well as locations of many faults shown on Plate 21, are from interpretation of data from the geophysical survey.

The most prominent structural feature in Surprise Valley is the Surprise Valley fault. This fault extends from near Fort Bidwell southerly along the base of the Warner Mountains to Duck Flat, in Nevada, a distance of about 60 miles. Movement along this fault probably began about five million years ago. Since that time, there has been over 5,000 feet of vertical displacement, resulting in the creation of a rugged fault scarp along the eastern front of the Warner Mountains. An idea of the magnitude of vertical displacement along this fault can be had by noting that the Miocene lava flows exposed at an elevation of about 4,500 feet north of Cedar Plunge are probably the same flows which cap Eagle Peak at an elevation of 9,883 feet.



See Plote 21 for locotion of section.

Figure 20. GENERALIZED GEOLOGIC SECTION A-A'
SURPRISE VALLEY GROUND WATER BASIN

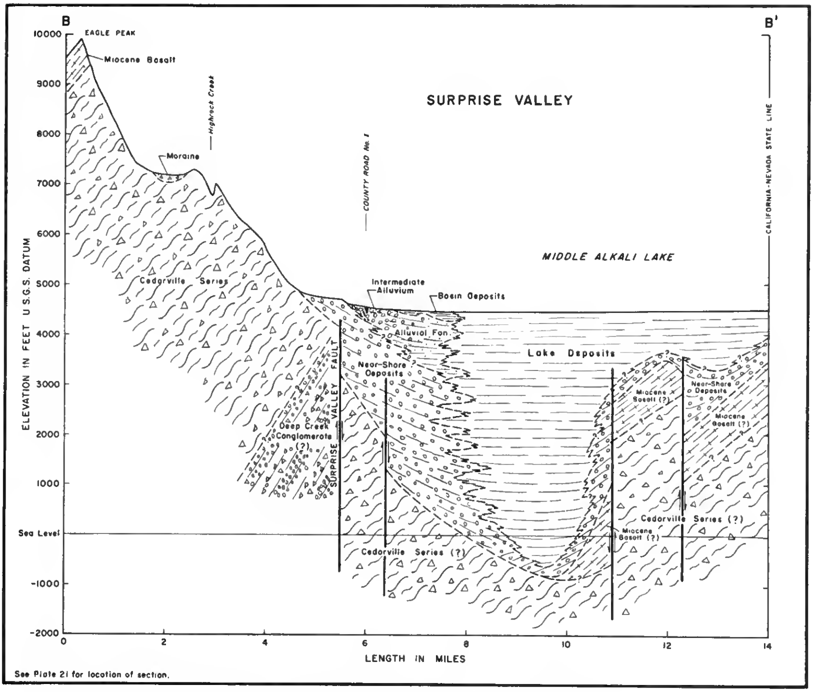


Figure 21. GENERALIZED GEOLOGIC SECTION B-B'
SURPRISE VALLEY GROUND WATER BASIN

Many faults in Surprise Valley affect ground water movement and quality. Some of them act as barriers to ground water movement either by offsetting permeable beds against those of lower permeability or by the creation of an impermeable gouge zone. Faults of this type may be partly responsible for confinement of ground water. Many of the faults indicated by dotted lines on Plate 21 are probably in this category. Other faults, notably those crossing areas of basalt, tend to create a permeable, gouge-free zone. These zones serve as paths for the downward and lateral percolation of subsurface water and thus allow water to move from areas of recharge to the deeper sediments in the valley. Some of the faults which pass beneath the valley floor have broken, permeable zones which go deep into the bedrock and serve as paths for the upward migration of superheated steam and water. Hot springs, such as occur at Cedar Plunge, Old Leonard Baths, and Menlo Baths, are the result.

Recharge and Movement of Ground Water

In Surprise Valley ground water basin, ground water moves from the mountains toward the lakes which occupy the central portion of the valley floor. Recharge to ground water on the west side of the valley is from infiltration of surface water into the apexes of the alluvial fans located below the mouths of canyons along the base of the Warner Mountains. In the extreme northern portion of the valley floor, surface water from the north infiltrates the coarse stream deposits and recharges the underlying ground water bodies. As these recharge areas are all within the valley floor area, no true upland recharge areas exist along the western and northern sides of Surprise Valley.

There are extensive upland recharge areas along the eastern side of the valley, as shown on Plate 22. These areas are composed of sediments of the Forty-nine Camp formation and the overlying Miocene basalt. Topographic and geologic conditions appear favorable for some subsurface inflow of ground water into Surprise Valley from Long Valley, Nevada. Farther south, subsurface inflow of ground water to Surprise Valley apparently comes from the northern portion of Duck Flat, Nevada. Along the southwestern margin of the valley, outcrops of Plio-Pleistocene basalt probably afford some opportunity for recharge to the ground water bodies within this portion of the valley.

The Warner Mountains act as a barrier to the general northeasterly direction of movement of most major storms in this part of California. Moist air masses tend to drop precipitation on the mountain range, but not in Surprise Valley on the lee side of the range. The Hays Canyon Range produces another storm barrier action, but the magnitude of precipitation produced is less than that effected by the Warner Mountains. This unequal precipitation

pattern caused by the two mountain ranges and other upland areas surrounding Surprise Valley has resulted in unequal distribution of available irrigation water and related agricultural development.

Mean seasonal precipitation varies from 16 to 10 inches from the north to the south edge of the valley floor and increases generally with increased elevation on the east side of the Warner Mountains to in excess of 32 inches on the higher peaks. On the valley floor, in the region of Lower Alkali Lake, the mean seasonal precipitation ranges from less than 6 inches along the east edge of the lake bed, to about 10 inches at the base of the Warner Mountains, and to about 8 inches at the base of the Hays Canyon Range. The precipitation on the valley floor generally increases in the northerly direction. On the Upper Alkali Lake portion of the valley floor, the minimum mean seasonal precipitation of less than 10 inches occurs along the east edge of the lake bed. Near the base of the Warner Mountains, the precipitation is 16 inches, while near the California-Nevada state line, it is about 12 inches.

Published records from precipitation stations located at Fort Bidwell and Cedarville date from the present back to 1866 and 1894, respectively. The recorded maximum and minimum seasonal precipitation at Fort Bidwell is 34.02 inches during the 1876-77 season and 7.69 inches during the 1932-33 season, respectively. The similar extreme values at the Cedarville station are 21.17 inches during the 1937-38 season and 7.04 inches during the 1932-33 season, respectively.

Most of the precipitation on the upland areas surrounding Surprise Valley is in the form of snow. Snow surveys in this area have been conducted annually since 1930. The water content of the snow at the Cedar Pass course averages 16.9 inches while the maximum and minimum values on April 1, are 33.6 inches during 1952 and 1.0 inches during 1934.

The generalized lines of equal elevation of water in wells shown on Plate 22 were used to determine the general direction of movement of ground water within the major portion of the Surprise Valley ground water basin. Within the eastern portions of the basin for which lines of equal elevation are not shown, the general direction of ground water movement is probably westerly from the foothills toward the lakes.

The lakeward direction of ground water movement results in the division of Surprise Valley ground water basin into three ground water subbasins. These subbasins are named with respect to the lake in which the movement of ground water terminates, namely, Upper Alakli Lake subbasin, Middle Alkali Lake subbasin, and Lower Alakli Lake subbasin. The ground water divides located between each of the three lakes are the result of the lakeward movement of ground water. Because a ground water divide is subject to change in location, the surface water drainage divide between each of the lakes is considered as the subbasin boundary. Plate 22 shows these subbasins and their respective boundaries.

Lines of equal elevation of water in wells are shown on Plate 22. One outstanding ground water characteristic of the west side of Surprise Valley is the extensive portion of this area within which the piezometric surface is above ground surface. The piezometric surface probably represents a composite of numerous, partially interconnected, confined ground water bodi Each body is more or less restricted to the alluvial fan and/or associated materials within which recharge takes place. Within any one alluvial fan, or fan complex, there is generally more than one confined ground water body. But primarily because the recharge area for each ground water body is more or less at the same elevation, the piezometric surface of each body approximates a similar shape and elevation. Within the western portion of the valley,

there are known exceptions to the above generalization concerning multiple aquifers. These exceptions, particularly in the area west of The Island in Middle Alkali Lake, are disclosed by the elevation of the piezometric surface at a few wells being considerably different from the piezometric surface shown on Plate 22.

An essentially unconfined, near-surface ground water body is present throughout most of the valley floor area. Along the north, west, and south sides of the valley floor, the configuration of the water table approximates that of the piezometric surface shown on Plate 22, but is at an elevation varying from ground surface to 50 or more feet below ground surface. Within this portion of the valley, the pumpage from this near-surface ground water body is, and will probably continue to be, relatively minor as compared to pumpage from the deeper, confined ground water bodies. Along the east side of the valley, ground water elevations are available only in the vicinity of Cedar Plunge. Here, near-surface ground water is presently the principal ground water body utilized. Its use in the future is expected to diminish in favor of deeper, confined ground water bodies. The generalized lines of equal elevation of both the near-surface and a deeper, confined ground water body in the vicinity of Cedar Plunge are shown on Plate 22. Within this area, the upper, essentially unconfined, ground water body is intercepted by wells of 60 feet or less in depth. Deeper wells, usually in excess of 90 feet, intercept the underlying confined ground water body. The primary recharge to ground water within both of these bodies is apparently from the alluvial fans of Sand Creek and Forty-nine Creek. The direction of movement of both ground water bodies is southwesterly toward Middle Alkali Lake.

Heated, mineralized ground water rises along certain faults in Surprise Valley. In some areas, this thermal water appears at the ground

surface at hot springs, and in other areas is tapped by hot water wells. The probable areas where this thermal water may adversely affect the quality of ground water is discussed in the water quality portion of this report.

Present Use

Approximately 33,000 acres of the 223,000 acres of valley floor lands in the California portion of the Surprise Valley ground water basin are irrigated at the present time. Only a very small percentage of these irrigated lands are located on the east side of the valley floor. Both poor soil conditions and insufficient surface water have limited agricultural development on this side of the valley floor.

The level of agricultural development in the California portion of the valley floor lands is limited primarily by the availability of surface water supply. The present supply is derived essentially from the diversion of nonregulated streamflow. Ground water development for irrigation use has increased substantially during recent years. Of the 522 wells located within the California portion of the basin, 58 wells are used for irrigation purposes. Most of the non-irrigation wells are either flowing stockwatering wells or domestic wells. The yield of ground water from irrigation wells generally ranges from 300 to 2,800 gallons per minute. The highest reported discharge from a nonpumping flowing well is 1,200 gallons per minute.

Ground Water Development Potential

Within the California portion of the valley floor area of Surprise Valley, all four zones of potential for development of ground water are present. The area of the valley floor in each classification is shown on Plate 23. The general conditions which presently govern the potential for development of ground water within each zone found in this basin are discussed

below. Available information is insufficient to determine the classification of lands along the east side of the valley, but the known factors pertaining to development of ground water along this side of the valley are presented following the discussion of the four zones.

"A" Zone. The "A" Zone areas in Surprise Valley are underlain by fairly permeable materials that receive adequate recharge. The "A" Zone areas south of and near Cedarville contain near-shore deposits overlain by alluvial fans. Large quantities of surface water from streams draining the Warner Mountains infiltrates the alluvial fans at the mouths of the canyons and percolates into the near-shore deposits.

The "A" Zone area at the north end of the valley is underlain by near-shore and alluvial fan materials along its western side, intermediate alluvium in its middle portion, and Forty-nine Camp formation along its eastern side. The western side of this zone possesses a good recharge opportunity from water infiltrating channel materials of Bidwell Creek and Mill Creek. The recharge opportunity to ground water in the central and eastern portions of this zone appears adequate for additional ground water development, but not to the extent of the other "A" Zone areas within the valley.

"B" Zone. Much of the irrigable lands along the west side of Surprise Valley are classified as "B" Zone. These "B" Zone areas are underlain by near-shore, alluvial fan, and other sediments which are somewhat thinner and/or less permeable than similar materials underlying the "A" Zone areas. The recharge opportunity of the "B" Zone areas is generally somewhat less than for the "A" Zone areas.

The "B" Zone areas in the north and south portions of the valley are considered to have the lowest development potential of the lands classified as "B" Zone. This is based on the fact that the overall permeability of

the underlying intermediate alluvium and basin deposits is generally less than that of the adjacent, more permeable alluvial fan and near-shore deposits.

"C" Zone. The alluvial fan, intermediate alluvium, and near-shore deposits located in "C" Zone areas near the margin of the valley floor are quite thin. Ground water bodies in these areas are not sufficiently thick for development of high yielding irrigation wells, but well yields should be sufficient for domestic and stockwatering uses.

"D" Zone. The "D" Zone areas are of two basic types. One type, located adjacent to the lakes, is composed of basin deposits underlain at depths of less than 50 feet by relatively impermeable lake deposits. Any water in wells located in these "D" Zone areas would be derived primarily from surficial materials and/or from the waters of the adjacent lake. The other type of "D" Zone area is located adjacent to outcrops of impermeable rock. Surface materials here may be quite permeable, but because they are underlain at shallow depths by impermeable rock, wells in these "D" Zone areas would yield little, if any, ground water.

East Side Valley Lands. At the present time, ground water development along the east side of Surprise Valley is relatively minor. However, there appears to be a relatively good potential for further development of ground water in areas underlain by the Forty-nine Camp formation and Miocene basalt. The subsurface extent of the Forty-nine Camp formation is not known, but it is suspected to underlie much of the east side of the valley north of Old Leonard Baths. Available precipitation will limit recharge to ground water in this area and thus preclude any extensive development of sustained yield from wells.

General. Insufficient data are available to formulate an opinion of the ground water development potential along the east side of the floor of Surprise Valley. Throughout the remainder of the California portion of the

valley floor, except for areas occupied by the lake beds, the ground water development potential, in general, is in excess of the present use of ground water. The extensive alluvial fans along the west side of the valley floor, and the Recent sediments underlying the northern and southern ends of the valley floor are fairly permeable and are sufficiently recharged to permit an increased amount of ground water development. Within specific areas, the recharge is excellent and the development potential is considered sufficient to develop high yielding wells. Except for valley floor areas immediately adjacent to impermeable rocks, or adjacent to the lake beds, the ground water development potential for domestic and stockwatering uses appears favorable throughout most of the valley floor lands.

Ground Water Storage Capacity

The ground water storage capacity to a depth of 400 feet has been estimated to be approximately 4,000,000 acre-feet. How much of this quantity is usable, or how much usable storage exists below 400 feet is not presently known. It is reasonable to assume that a significant amount of ground water could be developed.

Quality of Ground Water

Ground waters in Surprise Valley display a wide range of mineral quality. The ground waters located west of Lower and Middle Alkali Lakes and extending north as far as Lake City are usually excellent in quality and generally range from calcium to sodium bicarbonate in character. These waters are suitable for most beneficial uses. In the area east of Middle Alkali Lake and along the southern and western edges of Upper Alkali Lake, there are many thermal artesian wells and hot springs which yield poor quality waters. These waters range from sodium sulfate to sodium sulfate chloride in character. Except for these thermal waters, the remainder of

the ground waters located west of Upper Alkali Lake and those located north of the lake are generally of excellent mineral quality and suitable for most beneficial uses. These waters range from sodium to calcium bicarbonate in character. Insufficient data are available to establish the quality of ground water east of Upper Alkali Lake and along the east side of the valley south of Forty-nine Creek.

Water Quality Problems

The thermal artesian wells and hot springs in this valley yield waters high in electrical conductivity and contain high concentrations of sulfate, boron, fluoride, and sodium. Some of these waters also contain excessive arsenic. These waters are considered hazardous for both domestic and irrigation use. The location where these waters are found is shown on Plate 23. As these highly mineralized waters are artesian, they are under sufficient pressure to readily migrate through improperly constructed or maintained wells into adjacent good quality waters. Good well construction and sealing practices can keep this threat to a minimum. Increased ground water extractions and the resultant depression of water levels might also lead to the migration of these poor quality waters into adjacent areas of good quality ground water.

The surface waters in the Alkali Lakes are also very poor in quality and unsuitable for most beneficial uses. Changes in water levels may reverse existing ground water gradients so that the poor quality lake waters could migrate into and impair adjacent ground waters.

A few wells and springs associated with the fault zone west of Lower Alkali Lake yield waters containing excessive concentrations of fluoride or boron. There are a few additional wells not associated with the fault zone which also contain excessive concentrations of fluoride or boron, but these appear to be only local impairments.

Conclusion

At the present level of agricultural development, additional quantities of irrigation water to supplement streamflow are usually required during a portion of the growing season. The present irrigation water supply is derived primarily from snowmelt in the Warner Mountains. Snowmelt and resultant rapid runoff usually take place only during the beginning of the growing season. Thus, additional irrigation water may be required as early as the first of May in some areas and not until July in others. As the general steepness of the east side of the Warner Mountains precludes the construction of sufficient surface water storage facilities, and as importation of water appears infeasible, ground water appears to be the only logical source of additional supplemental irrigation water. Fortunately, large quantities of available ground water underlie most of the areas requiring supplemental irrigation water. But, two possible detrimental conditions need to be considered. The first is that poor quality water will probably be encountered in the area indicated on Plate 23. The second is that although available recharge apparently is not a limiting factor under the present level of ground water development, there are indications that such a condition will arise with increased use unless additional recharge facilities are constructed. Insufficient data concerning the east side of the valley floor are available to form an opinion of the ground water development potential of this area, except for the quality of ground water underlying the area northerly from Cedar Plunge. Along the east side of the valley floor, the main water-bearing formation appears to be the Forty-nine Camp formation. A preliminary opinion concerning this formation is that it will yield moderate quantities of ground water to wells, but recharge of this formation is insufficient for a sustained high level of ground water development.

It is concluded that the basic data collection activities of the Department of Water Resources should be continued in order to facilitate future quantitative and qualitative analyses of the ground water basin. Encouragement should be offered to local agencies in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

Madeline Plains Ground Water Basin

Madeline Plains ground water basin is located in northeastern Lassen County and consists of Madeline Plains, Dry Valley, and Grasshopper Valley. The valley floor of Madeline Plains is unusually flat and lies at an elevation which ranges from about 5,285 feet to 5,300 feet. Madeline Plains is roughly "L" shaped. The north-south segment, which constitutes the Madeline ground water subbasin is about 16 miles long and from 5 to 8 miles wide. The east-west segment named the Ravendale subbasin, is about 17 miles long and about 8 miles wide. The boundary between the two subbasins is near Terma, as shown on Plate 25. To the west of the Madeline subbasin is the Dry Valley subbasin, which is an elongated valley about 7 miles long and 1 mile wide. The floor of Dry Valley lies at an average elevation of about 5,290 feet. It is partially separated from Madeline subbasin by Dry Valley Ridge, which rises to an elevation of about 6,000 feet. Grasshopper Valley subbasin lies to the west of Dry Valley subbasin. The floor of Grasshopper Valley is about 9 miles long and 3 miles wide; it lies at an average elevation of about 5,300 feet. Grasshopper Ridge, which rises to an elevation of about 5,800 feet, partially separates Grasshopper Valley from Dry Valley.

A rugged, mountainous area completely surrounds Madeline Plains, Dry Valley, and Grasshopper Valley. The mountains are dominated by the old volcanic cones of Observation Peak, elevation 7,964 feet, McDonald Peak, elevation 7,931 feet, and Heavey Mountain, elevation 6,564 feet.

Madeline Plains is a basin of internal drainage; it has no surface outlet. Streams in the Madeline Plains area flow only intermittently during or immediately following periods of rainfall.

Surface exposures of various geologic formations of the Madeline Plains area are shown on Plate 24, Areal Geology, Madeline Plains Ground Water Basin. Plate 25, Generalized Lines of Equal Elevation of Water in Wells in Aquifers, Madeline Plains Ground Water Basin, Spring 1960, is a generalized picture of the elevation of ground water within the ground water basin. Plate 26, Potential for Development of Ground Water, Madeline Plains Ground Water Basin, presents the preliminary evaluation of the potential for ground water development within this basin.

Geologic History

In the Miocene epoch, about 25 million years ago, the Madeline Plains area was probably characterized by extensive rolling plains, scattered lakes, and occasional volcanic cones. By the Pliocene epoch, the area had become the location of an immense lake which stretched far to the north and south of the area. This lake was bordered by volcanic mountain ranges of unknown extent and height.

During the Pliocene epoch, the crust of the earth began to shift along numerous faults. At the same time, lava welled up along fissures formed by these faults and spread over much of the lake bed. New volcanoes slowly began to be built around the fissures and released billowing clouds of ash and glowing streams of lava.

The volcanoes continued to erupt in the Pleistocene epoch and then their activity diminished and finally ceased. The most prominent of these extinct volcanoes today are McDonald Peak, Observation Peak, and Heavey Mountain.

During the early Pleistocene epoch, drainage from the Madeline Plains area became blocked by lavas. Subsequently, a lake formed and grew in size until it attained a depth of about 120 feet and had a water surface

elevation of 5,400 feet. This lake, named Lake Madeline, covered all of Madeline Plains, Dry Valley, and Grasshopper Valley. For a short time, the lake is believed to have overflowed across the lava field south of Ravendale and into Secret Valley by way of Snowstorm Canyon. At the close of the Pleistocene epoch, the climate became drier, and the lake slowly dried up. Today all that remains of Lake Madeline is its dry lake bed.

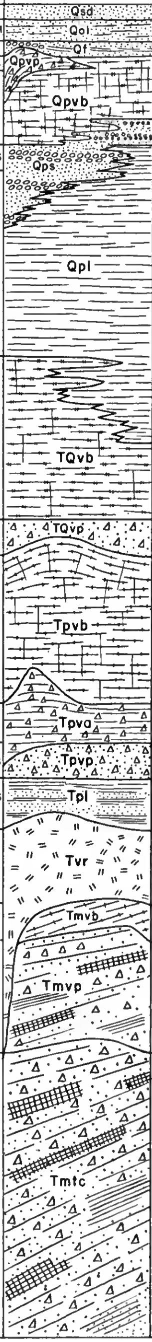
Water-Bearing Formations

Table 15 briefly describes the geologic formations in the Madeline Plains area. Of these, the principal water-bearing formations are Plio-Pleistocene and Pleistocene lava flows, Pleistocene lake and near-shore deposits, and Recent valley sediments.

Plio-Pleistocene and Pleistocene Lava Flows. Plio-Pleistocene and Pleistocene lavas form the extinct volcanoes and the lava fields surrounding much of Madeline Plains, Dry Valley, and Grasshopper Valley. Here, the lavas form extensive upland recharge areas. The lavas also underlie the valley floor areas, where they are interbedded with lake deposits. In these latter areas, because the lavas are moderately to highly permeable, they serve as important aquifers and are capable of yielding large quantities of ground water to wells.

Pleistocene Lake and Near-Shore Deposits. Fine grained lake deposits are present in the central portions of Madeline Plains, Dry Valley, and Grasshopper Valley. The flat-lying lake deposits are of low permeability and may be as much as 1,000 feet in thickness. Because of their low permeability, the lake deposits act as confining beds to ground water contained in interbedded basalt flows. The lake deposits themselves usually yield sufficient water only for domestic and stockwatering purposes.

GEOLOGIC FORMATIONS IN MADELINE PLAINS



GEOLOGIC AGE				GEOLOGIC FORMATION	STRATIGRAPHY	APPROXIMATE THICKNESS IN FEET	PHYSICAL CHARACTERISTICS	WATER-BEARING CHARACTERISTICS
CENOZOIC	QUATERNARY	RECENT		SAND DUNES	Qsd	0-25	Qsd: Unconsolidated, wind-blown sand.	Highly permeable and located above water table; hence acts only to recharge underlying materials.
				INTERMEDIATE ALLUVIUM	Qal	0-100	Qal: Unconsolidated silt, sand, gravel, and clay.	Moderately permeable. Yields moderate quantities of ground water to shallow wells.
				ALLUVIAL FANS	Qf	0-50	Qf: Unconsolidated, poorly sorted silt, sand, and gravel, with some clay.	Moderately permeable. Yields moderate quantities of ground water to shallow wells.
		PLEISTOCENE	PLEISTOCENE VOLCANIC ROCKS	PYROCLASTIC ROCKS	Qpvp	150	Qpvp: Unconsolidated volcanic fragments occurring as cinder cones.	Highly permeable but of small areal extent; thus of little importance to ground water.
				BASALT	Qpvb	50-250	Qpvb: Highly jointed vesicular basalt flows. Contains numerous scoria zones.	Permeability ranges from moderate to high. May provide large quantities of water to wells. Acts as recharge area.
				NEAR-SHORE DEPOSITS	Qps	0-75	Qps: Slightly consolidated beach deposits of sand and gravel with minor amounts of silt and clay.	Moderately permeable; yields moderate supplies of water to shallow wells.
				LAKE DEPOSITS	Qpl	0-1000	Qpl: Slightly to moderately consolidated clay, silt, and fine sand with interbedded buried lava flows. Alkali often present.	Low permeability. Generally yields small quantities of water to wells; may yield large quantities of water to wells intercepting buried lava flows.
	QUATERNARY / TERTIARY	PLIO-PLEISTOCENE	PLIO-PLEISTOCENE VOLCANIC ROCKS	BASALT	TQvb	?	TQvb: Cones and flows of jointed, vesicular basalt. Some flows are interbedded with lake deposits.	Highly permeable. Buried flows provide large amounts of ground water to wells. Acts to recharge adjacent valley areas.
				PYROCLASTIC ROCKS	TQvp	?	TQvp: Beds of semi-consolidated tuff and cinders.	Of little importance to ground water.
	TERTIARY	PLIOCENE	PLIOCENE VOLCANIC ROCKS	BASALT	Tpvb	?	Tpvb: Flows of jointed, vesicular basalt.	Of moderate permeability. Locally provides water to springs.
				ANDESITE	Tpva	?	Tpva: Plugs and flows of platy andesite.	Low permeability and of little importance to ground water.
				PYROCLASTIC ROCKS	Tpvp	?	Tpvp: Pale-colored, bedded tuff.	Low permeability and of little importance to ground water.
				PLIOCENE LAKE DEPOSITS (Tuledad Formation)	Tpl	?	Tpl: Pale-colored ash-rich and tuffaceous beds. Outcrops only in Tuledad Valley.	Low to moderate permeability. May yield moderate quantities of water to domestic and stock wells.
				RHYOLITE	Tvr	?	Tvr: Light-colored, massive rhyolite.	Essentially impermeable.
		MIOCENE	MIOCENE VOLCANIC ROCKS	BASALT	Tmvb	?	Tmvb: Flows of jointed basalt.	Low permeability and of no importance to ground water.
				PYROCLASTIC ROCKS	Tmvp	1000	Tmvp: Bedded mudflows, tuff, ashy sandstone, and diatomite. May be correlative to part of Turner Creek formation.	Of low overall permeability. A few more permeable beds may yield limited quantities of ground water to domestic and stock wells.
				TURNER CREEK FORMATION	Tmtc	4000	Tmtc: Massive mudflows and tuffs with beds of ashy sandstone and diatomite. Includes minor flows of basalt and andesite.	Of low overall permeability. A few more permeable beds may yield limited quantities of ground water to domestic and stock wells.

Coarse grained near-shore deposits form a narrow strip around the margins of Madeline Plains, Dry Valley, and Grasshopper Valley. The deposits are estimated to be about 75 feet thick; however, in many cases they consist of a thin veneer only a few feet thick overlying older materials. The near-shore deposits are moderately permeable, but because most of them occur above the water table, they serve primarily as recharge areas. Locally, the deposits may be capable of yielding moderate amounts of water to shallow wells.

Recent Valley Sediments. Recent valley sediments include alluvial fans and intermediate alluvium found around the margins of the valley floor areas. Both deposits are quite limited in areal extent and seldom exceed 100 feet in thickness. Alluvial fans occur below the mouths of canyons and are of moderate permeability. Although the intermediate alluvium generally is finer grained, it is also moderately permeable. Both types of deposits yield moderate amounts of water to shallow wells.

Influence of Geologic Structure on Ground Water

The principal structure affecting ground water in the Madeline Plains area is the layered, sloping lavas which radiate outward from the extinct volcanoes. The layers contain permeable zones along which ground water moves from areas of recharge to and beneath the valley floor areas.

The northeastern and southwestern portions of the Madeline Plains area shown on Plate 24 is transected by roughly parallel faults trending in a north-south direction. These faults appear to have only minor effects on ground water in Madeline Plains ground water basin. One effect is the exposure of relatively impermeable pyroclastic rocks along the eastern edge of Madeline Plains. Another group of faults crosses much of the remaining area shown on Plate 24. This group is oriented in a northwest-southeast direction. The Likely fault, one of the larger faults in Northeastern

California, is one of this group. Movement along several of the parallel faults of this group has uplifted the ridges that separate Grasshopper Valley, Dry Valley, and Madeline Plains subbasins. These ridges may partially restrict ground water movement between the subbasins.

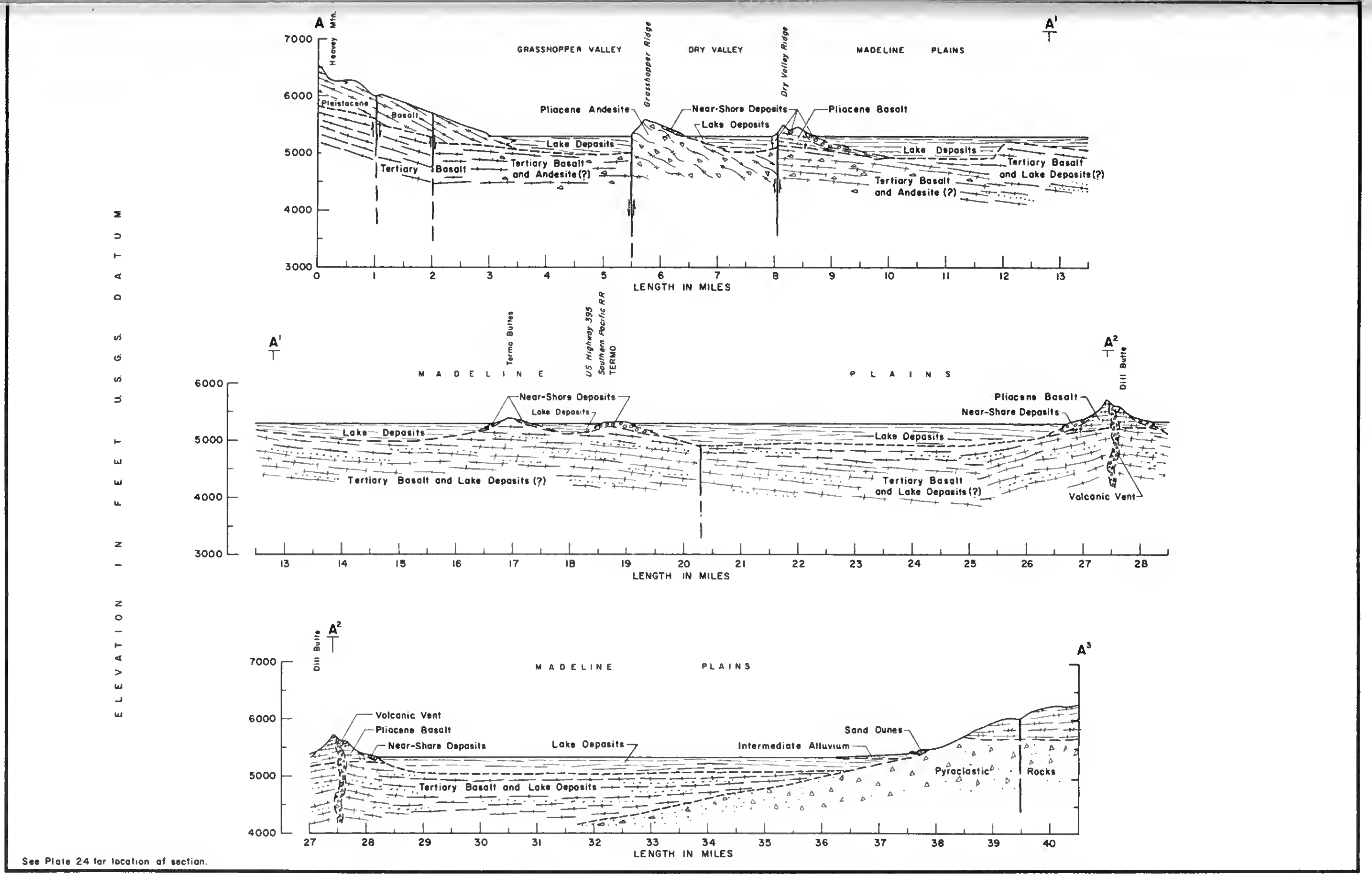
It is not known how many faults pass beneath the floor of Madeline Plains. Geologic section $A-A^1-A^2-A^3$, presented on Figure 22, shows the probable geologic structural conditions to a depth of 1,500 feet below the ground surface. Geologic Section $B-B^1$, presented on Figure 23, shows the probable geologic structural conditions southwest of the town of Madeline.

Recharge and Movement of Ground Water

The recharge areas, shown on Plate 25, consist of Plio-Pleistocene basalts. Precipitation which infiltrates the recharge areas percolates downward and then laterally to recharge the ground water basin. Wells located in certain portions of the upland recharge areas may yield sufficient amounts of water for stock and domestic uses. Portions of the upland recharge areas supply springs which flow from joints and fractures in the lavas surrounding the valley floor areas. These springs, especially those in the southern and western parts of Grasshopper Valley, contribute a portion of their flow to the ground water body by infiltration in the valley floor below the springs.

Mean seasonal precipitation ranges from 10 to 12 inches per year over most of the valley floor and from 12 to 14 inches per year over the recharge areas. Precipitation at the community of Madeline averages 11 inches per year with a recorded minimum and maximum of about 6 and 22 inches, respectively. Similar variations in year to year precipitation are to be expected throughout the Madeline Plains area.

Insufficient ground water elevation data were available to determine lines of equal elevation of water in wells for Grasshopper and Dry Valley subbasins and for much of the Madeline and Ravendale subbasins.



See Plate 24 far location of section.

Figure 22. GENERALIZED GEOLOGIC SECTION A-A¹-A²-A³
MADELINE PLAINS GROUND WATER BASIN

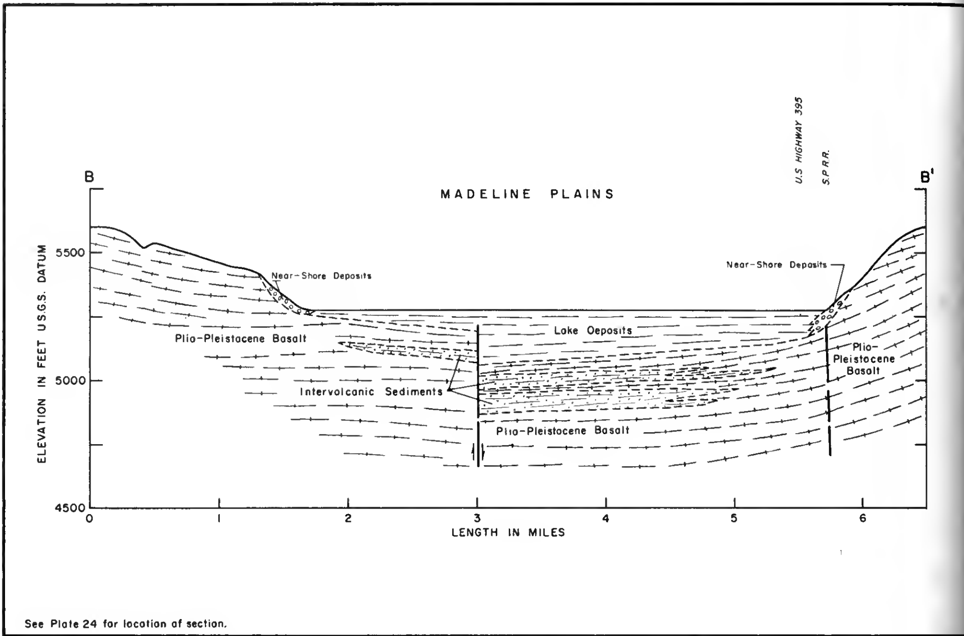


Figure 23. GENERALIZED GEOLOGIC SECTION B-B'
MADELINE PLAINS GROUND WATER BASIN

Present Use of Ground Water

At the present level of agricultural development of the 180,000 acres of valley floor lands in the Madeline Plains ground water basin, only 6,000 acres are irrigated. These lands receive irrigation water primarily from the diversion of springs, partially regulated streamflow, and surface water storage. Pumped ground water is used in some areas as a supplemental irrigation water supply. Only six of the 91 water wells located within the basin have been classified as irrigation wells. The remaining wells are used primarily for domestic and stockwatering purposes.

The maximum reported yield from a well within the basin is 3,800 gallons per minute. However, this yield is far greater than the average yield of about 600 gallons per minute produced by irrigation wells in Madeline Plains. Yields from domestic and stock wells are much lower.

Ground Water Development Potential

Within the valley floor area of the Madeline Plains ground water basin, all four zones of potential for development of ground water are present. The area of the valley floor in each classification is shown on Plate 26. Available ground water data were insufficient to determine the potential for ground water development in certain areas; however, these areas are expected to range from "B" to "C" in ground water development potential. The general conditions which presently govern the potential for development of ground water within each zone found in this basin are discussed below.

"A" Zone. The "A" Zone area shown on Plate 26 is bordered by a recharge area over which moderate precipitation occurs. Its classification as "A" Zone is based primarily upon a reported yield of 3,800 gallons per

minute from a well located within this area. This well intercepts buried lava aquifers interbedded within the lake deposits. Properly constructed and developed wells several hundred feet in depth which intercept lava aquifers should produce high yields of ground water.

"B" Zone. Four scattered areas in the Madeline Plains ground water basin fall within the "B" Zone classification. All four areas depend on underlying aquifers having reasonably high permeabilities and proximity to good recharge areas. The "B" Zone area in the northern part of the Madeline subbasin may be partially recharged by surface water irrigation return flow. Properly constructed and developed wells drilled to depths of several hundred feet into intermediate alluvium, buried lavas, and near-shore deposits should result in supplies sufficient for most irrigation requirements.

"C" Zone. Wells located in the "C" Zone areas have only a fair development potential. Limited irrigation yields are possible, but should not be expected. However, the chance of the discovery of buried lava aquifers is possible, which could increase ground water production from these areas.

"D" Zone. The "D" Zone areas have the poorest ground water development potential, and wells located in this zone are not expected to produce more than limited supplies for domestic or stockwatering purposes. The location of a well near outcroppings of relatively impermeable pyroclastic rocks may result in the well producing little or no ground water.

General. The overall ground water development potential for Madeline Plains is only moderate. Although the opportunity for recharge is essentially good, precipitation in the drainage area is relatively low. Because of this it is believed that sustained yields from high capacity wells would result in mining of ground water rather than use followed by natural replenishment.

Ground Water Storage Capacity

The ground water storage capacity to a depth of 600 feet has been estimated to be approximately 2,000,000 acre-feet. How much of this quantity is usable, or how much usable storage exists below 600 feet is not presently known. It is reasonable to assume that a significant amount of ground water could be developed.

Quality of Ground Water

The ground water in Madeline Plains basin is generally of good quality and should be suitable for most beneficial uses. While bicarbonate is the predominant anion, no cation predominates although calcium and magnesium ions are more prevalent than is sodium. Insufficient data are available to evaluate the quality of ground water in Grasshopper or Dry Valleys.

Water Quality Problems

About one out of every four wells in this basin yields water which shows some localized impairment. Most of these waters have high electrical conductivities indicating high salinities. Several show excessive iron and boron concentrations.

The Madeline Plains ground water basin is a closed basin; thus increased use and reuse of water will probably result in progressive impairment of the quality of ground water. Ultimately the salinity of the ground water in this basin could increase to the point where the ground water becomes unsuitable for beneficial use.

Conclusion

Based upon the limited data available, the development of some supplemental irrigation supplies from the Madeline Plains ground water basin

appears to be promising. The relatively low precipitation over the entire drainage basin limits the possible recharge of the ground water basin. Adequate irrigation yields may be expected from the "A" and "B" Zone areas from properly constructed wells.

It is concluded that the basic data collection activities of the Department of Water Resources should be continued in order to facilitate future quantitative and qualitative analyses of the ground water basin. Encouragement should be offered to local agencies in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

Willow Creek Valley and Secret Valley Ground Water Basins

Willow Creek Valley and Secret Valley ground water basins are located in central Lassen County. The more westerly, Willow Creek Valley, has an average elevation of about 4,900 feet. It is roughly 7 miles long and 4 miles wide. The valley is bounded on the north by Horse Lake Mountain and on the west by Black Mountain, Deans Ridge, and Mahogany and Greens Peaks. On the southern boundary, Antelope Mountain and Susan Peak are found. Tunnison Mountain forms the eastern boundary. To the west, beyond Black Mountain, is Eagle Lake. Willow Creek, originating from springs northwest of Willow Creek Valley, flows southeasterly through the valley.

Secret Valley is located about 15 miles east of Willow Creek Valley. Secret Valley is about 9 miles long and 6 miles wide. The floor of the valley lies at an elevation of about 4,400 feet. The valley is bordered by Five Springs Mountain and the Skedaddle Mountains on the east and south, respectively, and by Snowstorm Mountain on the north. To the west is South Plateau, a broad lava field. Secret Creek originates north of Secret Valley, flows southwesterly through the valley, and continues southwesterly through Balls Canyon. The major tributary to Secret Creek is Snowstorm Creek, which flows into Secret Valley from the northwest.

Surface exposures of the various geologic formations of the Willow Creek Valley and Secret Valley area are shown on Plate 27, Areal Geology, Willow Creek Valley and Secret Valley Ground Water Basins. Plate 28, Generalized Lines of Equal Elevation of Water in Wells in Aquifers, Willow Creek Valley and Secret Valley Ground Water Basins, Spring 1960, is a generalized picture of the elevation of ground water in Willow Creek Valley ground water basin. No elevation data are available for Secret Valley ground water basin. Plate 29, Potential for Development of Ground Water, Willow Creek

Valley and Secret Valley Ground Water Basins, presents the preliminary evaluations of the potential for ground water development within Willow Creek Valley ground water basin. There were insufficient data available to determine the potential for ground water development in Secret Valley.

Geologic History

During the early Tertiary period, the Willow Creek Valley-Secret Valley region was a land of many volcanoes and lava fields. In the Pliocene epoch, the region became the site of a vast irregular lake which contained volcanic islands and probably was bordered by volcanic mountain ranges. During the middle or late Pliocene, the crust of the earth in the vicinity of Willow Creek Valley began shifting along faults. This movement was associated with continuing volcanism. In contrast, the Secret Valley area remained relatively stable except for the continued construction of volcanoes.

By the beginning of the Pleistocene epoch, Willow Creek Valley had formed and was receiving alluvial and volcanic debris. The northern part of the valley was subsequently covered by a large lava field. During the latter part of the Pleistocene epoch, Eagle Lake probably drained into Willow Creek Valley through a wide canyon north of Deans Ridge.

After the close of the Pleistocene epoch, volcanic activity caused Black Mountain, located between Eagle Lake and Willow Creek Valley, to increase in size. The mountain and associated lava flows eventually blocked the surface outlet of Eagle Lake. Lava also poured into the western portion of Willow Creek Valley. With this last eruption of lava, volcanism ceased in the Willow Creek Valley area; however, faulting and erosion have continued to shape the landscape up to the present time.

Secret Valley evolved in an entirely different manner. During the late Pliocene and early Pleistocene epochs, the area was one of intense

volcanism. Lavas spread over the old Pliocene lakebed, and large volcanoes constructed cones 2,000 to 3,000 feet above the intervening lava fields. Streams eventually eroded canyons through the lava field located between Snowstorm, Shaffer, and Skedaddle Mountains. Erosion by these streams re-exposed the Pliocene lakebeds. Once the relatively soft lakebeds were exposed by Snowstorm and Secret Creeks, the overlying lavas were easily undermined and the canyons slowly widened to form Secret Valley. Erosion has continued to broaden the valley throughout the Pleistocene and Recent epochs.

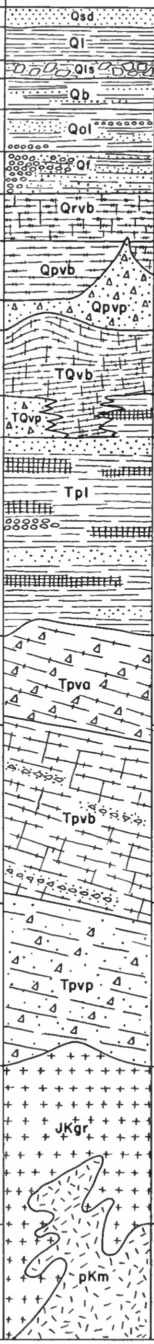
Water-Bearing Formations

Table 16 briefly describes the geologic formations in the Willow Creek Valley-Secret Valley area. Of these, the water-bearing formations are Plio-Pleistocene to Recent lava flows, Pliocene lake deposits, and Recent valley sediments.

Plio-Pleistocene to Recent Lava Flows. Moderately to highly permeable Plio-Pleistocene to Recent basalt flows cover extensive areas in the Willow Creek Valley-Secret Valley area. These lavas border most of Willow Creek Valley, except for the southwestern margin. The lavas form areas of ground water recharge and act as aquifers beneath the southeastern and perhaps the northern portions of the valley. The Recent lavas appear to transmit water from Eagle Lake into Willow Creek Valley, some of which probably appears at the numerous springs that feed Willow Creek.

Secret Valley is surrounded by Plio-Pleistocene and Pleistocene lavas. They form the low lying plateaus east and west of the valley and the volcanic cones to the north and south. The older lavas are interbedded with Pliocene lake deposits beneath the valley floor. These older lavas are the principal aquifers in Secret Valley and may yield large amounts of confined

GEOLOGIC FORMATIONS IN WILLOW CREEK VALLEY AND SECRET VALLEY



GEOLOGIC AGE	GEOLOGIC FORMATION	STRATIGRAPHY	APPROXIMATE THICKNESS IN FEET	PHYSICAL CHARACTERISTICS	WATER-BEARING CHARACTERISTICS
Cenozoic – Quaternary – Recent	SAND DUNES	Qsd	0-25	Qsd: Unconsolidated, thin deposits of wind-blown sand. Found only along shore of Eagle Lake.	High permeability but underlai by impermeable material. Of no importance to ground wate
Cenozoic – Quaternary – Recent	LAKE DEPOSITS	Ql	0-100	Ql: Unconsolidated silt and clay.	Very low permeability. Of ver little importance to ground water.
Cenozoic – Quaternary – Recent	LANDSLIDE	Qls	0-50	Qls: Unconsolidated sand, clay, and blocks of basalt.	Moderate permeability but of little importance to ground water.
Cenozoic – Quaternary – Recent	BASIN DEPOSITS	Qb	0-150	Qb: Unconsolidated silt, clay, sand, and organic muck.	Low permeability. Yields smal supplies of ground water to stock and domestic wells.
Cenozoic – Quaternary – Recent	INTERMEDIATE ALLUVIUM	Qal	0-250	Qal: In Secret Valley, unconsolidated sand, silt, and clay; up to 50 feet in thickness. In Willow Creek Valley, unconsolidated sand, silt, and lenses of gravel; up to 250 feet in thickness.	In Secret Valley, of low per ability and yields small amoun of water to wells. In Willow Creek Valley, mode ately permeable and yields moderate amounts of water to wells.
Cenozoic – Quaternary – Recent	ALLUVIAL FANS	Qf	0-250	Qf: In Secret Valley, unconsolidated gravel, fine sand, and clay; up to 50 feet in thickness. In Willow Creek Valley, unconsolidated gravel, sand, and clay; up to 250 feet in thickness.	In Secret Valley, of moderat permeability and yields modera amounts of water to wells. In Willow Creek Valley, of moderate to high permeability and yields moderate to large amounts of water to wells.
Cenozoic – Quaternary – Recent	RECENT BASALT	Qrvb	0-250	Qrvb: Highly fractured basalt containing many zones of scoria.	Highly permeable. Could trans mit large quantities of grou water to wells.
Cenozoic – Quaternary – Pleistocene – Pleistocene Volcanic Rocks	BASALT	Qpvb	0-100	Qpvb: Fractured flows of basalt containing zones of scoria.	Moderate to high permeability. Could transmit large amounts of ground water to wells. M contain confined water.
Cenozoic – Quaternary – Pleistocene – Pleistocene Volcanic Rocks	PYROCLASTIC ROCKS	Qpvp	0-250	Qpvp: Semiconsolidated cinders and tuff. Occurs mainly as cinder cones.	Of little importance to ground water.
Cenozoic – Quaternary/Tertiary – Plio-Pleistocene – Plio-Pleistocene Volcanic Rocks	BASALT	TQvb	?	TQvb: Cones and flows of jointed, vesicular basalt.	Highly permeable. Acts as recharge area. May provide large amounts of ground water to wells. May contain confined water.
Cenozoic – Tertiary – Plio-Pleistocene – Plio-Pleistocene Volcanic Rocks	PYROCLASTIC ROCKS	TQvp	?	TQvp: Pale-colored, bedded tuff.	Unimportant to ground water.
Cenozoic – Tertiary – Pliocene	PLIOCENE LAKE DEPOSITS	Tpl	1000	Tpl: Beds of consolidated shale, sandstone, diatomite, and lenses of gravel.	Low overall permeability. Yields sufficient water only for domestic and stock purposes. Gravel lenses moderately permeable and could provide moderate quantities of semiconfined ground water.
Cenozoic – Tertiary – Pliocene – Pliocene Volcanic Rocks	ANDESITE	Tpva	?	Tpva: Massive flows and plugs of andesite.	Unimportant to ground water.
Cenozoic – Tertiary – Pliocene – Pliocene Volcanic Rocks	BASALT	Tpvb	?	Tpvb: Highly jointed flows, dikes, and necks of basalt. Contains zones of scoria.	Moderate permeability. Could yield moderate amounts of co fined ground water to wells.
Cenozoic – Tertiary – Pliocene – Pliocene Volcanic Rocks	PYROCLASTIC ROCKS	Tpvp	?	Tpvp: Beds of consolidated tuff.	Unimportant to ground water.
Mesozoic – Jurassic to Cretaceous – Basement Complex	GRANITIC ROCKS	JKgr	?	JKgr: Hard, nonweathered granitic rocks. Soft, weathered, decomposed granite.	Where nonweathered, rock is essentially impermeable. Some water transmitted along joints. Where decomposed, rock is of low permeability, and capable of transmitting very small amounts of ground water.
Pre-Cretaceous – Basement Complex	METAMORPHIC ROCKS	pKm	?	pKm: Massive, metamorphosed andesite and rhyolite.	Essentially impermeable.

water to wells. The lavas surrounding Secret Valley act as upland recharge areas and give rise to numerous springs located along the northern edge of the valley.

Pliocene Lake Deposits. Pliocene lake deposits underlie all of Secret Valley and probably occur beneath a cover of several hundred feet of Recent sediments in Willow Creek Valley. In general, these deposits are of low overall permeability and act as aquicludes in Secret Valley, confining water in older flows in the Plio-Pleistocene basalt. The lake deposits themselves yield sufficient water only for domestic or stock purposes. A few gravel lenses are present in the lake deposits in Secret Valley. These lenses are moderately permeable and could provide moderate quantities of ground water to wells. The relative importance of the Pliocene lake deposits in Willow Creek Valley is not known at this time.

Recent Valley Sediments. Recent valley sediments in Willow Creek and Secret Valleys include basin deposits, alluvial fans, and intermediate alluvium. In Secret Valley, these deposits are generally very thin and tend to be of low permeability, and thus are of little importance to ground water. Locally, the materials provide sufficient water to shallow wells for domestic and stockwatering purposes. The intermediate alluvium and alluvial fans in Willow Creek Valley are up to 250 feet thick. The deposits are moderately to highly permeable and yield moderate to large amounts of water to wells. The deposits underlie most of the southwestern half of the valley. The northeastern part of the valley is mostly underlain by basin deposits which are low in permeability and are poor producers of ground water.

Influence of Geologic Structure on Ground Water

The geologic structures of Willow Creek Valley and Secret Valley are vastly different. Willow Creek Valley is a complexly faulted depression

controlled by a northwest-southeast fault system along its southwestern margin. The northwest-southeast system forms a series of stepped fault blocks along which the valley was depressed and the granitic rocks of Deans Ridge correspondingly elevated. The faults in Willow Creek Valley have little apparent effect on ground water. Generalized geologic section A-A[1], presented on Figure 24, shows the probable geologic structural conditions to a depth of about 1,200 feet below the valley floor.

Secret Valley, in contrast to Willow Creek Valley, is an erosional valley that has undergone very little modification by faulting. The principal structures affecting ground water are the layered, sloping lavas radiating from the centers of the extinct volcanoes north and south of the valley. The oldest of the lavas extend beneath the valley floor where they serve as important aquifers. The younger lavas occur only around the edge of the valley where they recharge springs and underlying older rocks. The Pliocene lake deposits in Secret Valley are gently folded. The effect that this folding has on ground water is unknown at the present time. Generalized geologic section B-B[1], presented on Figure 25, shows the probable geologic structural conditions to a depth of about 1,000 feet below the valley floor.

Recharge and Movement of Ground Water

Upland recharge areas, shown on Plate 28, are composed principally of Recent, Pleistocene, and Plio-Pleistocene basalts. Precipitation infiltrates the upland recharge areas and then percolates laterally into the valleys. Available precipitation data indicate that within the Willow Creek Valley drainage area, from 10 to 12 inches of mean seasonal precipitation can be expected, while in the Secret Valley drainage area, only 6 to 8 inches appear likely.

Willow Creek Valley ground water basin contains both unconfined and confined ground water bodies. Sediments which comprise most of the valley

fill are generally saturated to within a few feet of the ground surface and provide readily available supplies of ground water for stock and domestic use. Limited water level data indicate that ground water generally moves toward Willow Creek.

Flowing wells, which indicate the presence of confined aquifers, have been drilled in the southeastern part of the valley. It is believed that the confined aquifers are buried lava flows which may be Pleistocene basalt.

Although there are no ground water elevation data available for Secret Valley, it can be assumed that ground water generally moves from the upland area to and beneath the valley floor. It then moves toward Secret Creek and eventually leaves the valley by way of Balls Canyon. Some ground water may leave the valley by way of subsurface outflow beneath South Plateau.

Present Use of Ground Water

The portion of Willow Creek Valley ground water basin which is overlain by valley floor lands encompasses about 12,500 acres, all of which are classified as irrigable. The present available water supply, which is derived mostly from surface water, limits irrigation to about 4,000 acres. Only three irrigation wells have been located in the valley, and they are used to supplement available surface supply rather than irrigate additional lands. The best irrigation well in the valley is reported to have developed 1,200 gallons per minute. Only about ten domestic and stock wells have been located in the valley.

Secret Valley ground water basin contains about 22,000 acres of irrigable valley floor lands. At the present time there are about 3,000 irrigated acres in the valley. Most ground water in the valley is used for domestic and stockwatering purposes. However, there are at least two irrigation wells in the valley.

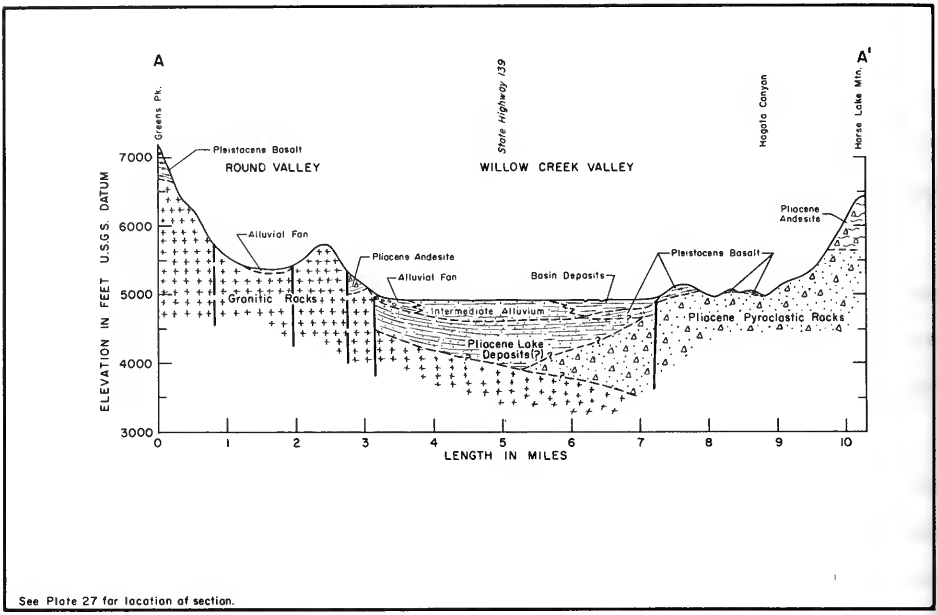


Figure 24. GENERALIZED GEOLOGIC SECTION A-A'
WILLOW CREEK VALLEY GROUND WATER BASIN

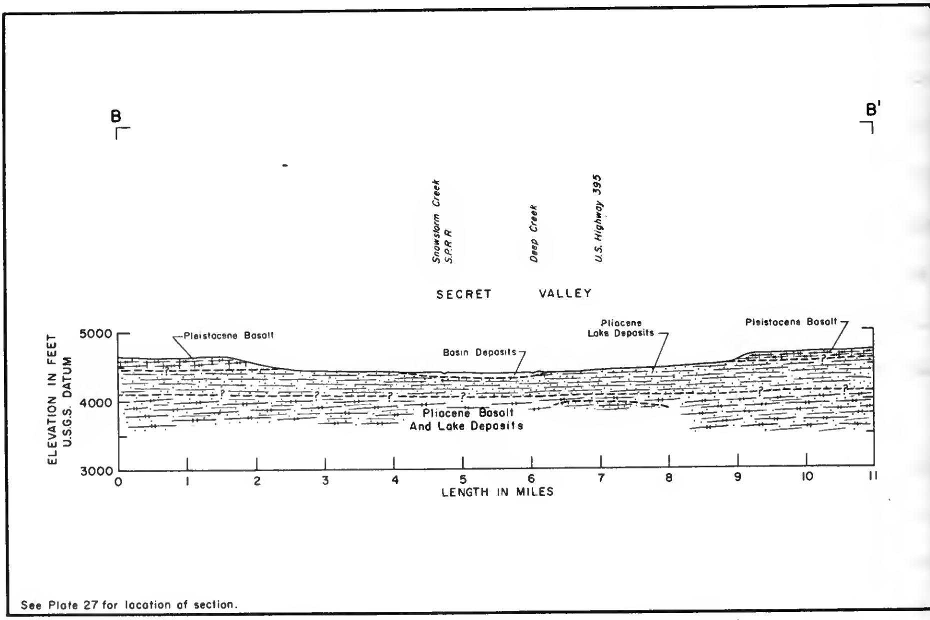


Figure 25. GENERALIZED GEOLOGIC SECTION B-B'
SECRET VALLEY GROUND WATER BASIN

Ground Water Development Potential of Willow Creek Valley

Within the valley floor area of Willow Creek Valley ground water basin, only the "B" and "C" Zones of ground water development potential are present. The area of the valley floor in each classification is shown on Plate 29. The general conditions which govern the potential in this basin are discussed below.

"B" Zone. Properly constructed wells up to several hundred feet in depth should be able to supply moderate quantities of ground water for most irrigation requirements from the alluvial fan and intermediate alluvium of the "B" Zone.

"C" Zone. Restricted irrigation yields are possible in the "C" Zone. If buried lava flows are intercepted, yields of ground water having the magnitude of those of the "B" Zone may be obtained.

General. The overall development potential for Willow Creek Valley is moderately good. The capacity for recharge of the ground water basin is excellent, but precipitation is relatively low. The aquifers in the ground water basin are quite thick. There is a possibility that subsurface inflow from Eagle Lake may contribute to the ground water within the Willow Creek Valley ground water basin. Quantities of ground water sufficient to satisfy ultimate irrigation requirements for Willow Creek Valley are probably available.

Ground Water Development Potential of Secret Valley

There are insufficient data available to classify the valley floor area of Secret Valley into the various zones of potential for ground water development. It is estimated that most of the valley floor area would fall in either the "B" or "C" Zone categories.

Quality of Ground Water

The ground water in Willow Creek Valley is generally excellent in quality. It is a well balanced water with no cation predominating; bicarbonate is the predominant anion. No data are available to determine the quality of ground water in Secret Valley.

Water Quality Problems

A single shallow well at the southeast end of Willow Creek Valley yields water that has a very high electrical conductivity and an excessive nitrate content. Water from this well is considered to be hazardous for domestic or irrigation use. This well, however, appears to represent only a localized condition of impairment. There are no other known or anticipated water quality problems in this valley.

Conclusion

Properly constructed wells within "B" Zone areas of Willow Creek Valley ground water basin should be capable of developing ground water in quantities sufficient for additional irrigation use. Wells in the "C" Zone areas generally have a lower potential for development of ground water and can be expected to supply only limited quantities of ground water for irrigation.

The recharge areas are extensive and highly permeable, but available precipitation appears to be insufficient to allow maximum utilization of potential ground water storage capacity.

It is concluded that the basic data collection activities of the Department of Water Resources should be continued in order to facilitate future quantitative and qualitative analyses of the ground water basin. Encouragement should be offered to local agencies in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

Honey Lake Valley Ground Water Basin

Honey Lake Valley ground water basin is located in eastern Lassen County and adjacent western Washoe County, Nevada. The valley is bounded by the Diamond Mountains on the west and southwest, the Fort Sage and Virginia Mountains on the southwest and southeast, Antelope Mountain and Shaffer Mountain on the north, and the Amedee and Skedaddle Mountains on the northeast. The California portion of Honey Lake Valley is about 45 miles in length and 10 to 15 miles in width. Honey Lake, which is usually dry during the summer months, covers an area of about 93 square miles and is a dominant feature of the valley. The floor of the valley ranges in elevation from less than 4,000 feet along the shore of Honey Lake to about 4,200 feet at the edge of the valley floor.

Major tributaries to the valley are Long Valley Creek, Susan River, and Willow Creek. Long Valley Creek drains a large arid region lying to the southeast of Honey Lake Valley. Susan River drains the volcanic plateau located to the west of Honey Lake Valley. Willow Creek drains Willow Creek Valley which lies to the north of the Honey Lake area.

Surface exposures of the various geologic formations of the Honey Lake Valley area are shown on Plate 30, Areal Geology, Honey Lake Valley Ground Water Basin. Plate 31, Generalized Lines of Equal Elevation of Water in Wells in Aquifers, Honey Lake Valley Ground Water Basin, Spring 1960, is a generalized picture of the elevation of ground water within the ground water basin. Plate 32, Potential for Development of Ground Water, Honey Lake Valley Ground Water Basin, presents the preliminary evaluations of the potential for ground water development within this basin. Areas of hazard because of poor quality water are also indicated on Plate 32.

Geologic History

At the beginning of the Tertiary period, 60 million years ago, the Sierra Nevada was probably a low range of hills. At some time during the Tertiary, the area now known as Honey Lake Valley slowly began to subside. By the Pliocene epoch, the valley and a large area to the north were covered by an immense body of water surrounded by active volcanoes. The lake may have had a northwesterly outlet to the sea. During the middle and late part of the Pliocene epoch, the crust of the earth began shifting along numerous faults, and the Diamond Mountains and the Sierra Nevada were tilted upward. Volcanic activity had ceased in the Diamond and Fort Sage Mountains, but volcanism became more active to the north and new volcanoes were built. The continued faulting and volcanism restricted the Pliocene lake so that it no longer had an outlet to the sea. Uplift along the Antelope Mountain fault during the late Pliocene and early Pleistocene epochs left a part of the old Pliocene lake bed perched about 1,000 feet above the present valley floor.

During the Pleistocene epoch, a second lake, named Lake Lahontan, covered all of Honey Lake Valley as well as adjacent areas of northwestern Nevada. Lake Lahontan had a maximum surface elevation of about 4,400 feet and a maximum depth of about 400 feet in the Honey Lake basin. The water surface of the lake probably fluctuated a great deal during the Pleistocene epoch. In fact the lake may have dried up during the interglacial stages only to reappear again during the succeeding glacial stages.

At the close of the Pleistocene epoch, volcanoes adjacent to Honey Lake Valley ceased to erupt and became dormant. With the beginning of the Recent epoch, the climate of the region gradually became more arid. Lake Lahontan slowly began to dry up until today only a few remnants are left, such as Honey Lake in California, and Pyramid and Walker Lakes in Nevada.

Water-Bearing Formations

Table 17 briefly describes the geologic formations in Honey Lake Valley. Of these, the principal water-bearing formations are Pliocene lake deposits, Plio-Pleistocene and Pleistocene lava flows, Lahontan lake and near-shore deposits, and Recent valley sediments.

Pliocene Lake Deposits. Pliocene lake deposits underlie nearly all of Honey Lake Valley and the lava fields found to the north. Most of the valley fill consists of these deposits, and they reach a maximum thickness of about 5,000 feet near the northwestern end of The Island. The deposits are usually covered by several hundred feet of Lahontan lake deposits and Recent valley sediments and thus are usually encountered only in deeper wells. In general, Pliocene lake deposits are of low permeability, but locally, may yield moderate quantities of confined water to wells.

Plio-Pleistocene and Pleistocene Lava Flows. Plio-Pleistocene and Pleistocene lavas form the lava fields and extinct volcanoes bordering Honey Lake Valley on the north. Some of the lavas are interbedded with Pliocene and Lahontan lake deposits. The lavas are moderately to highly permeable; and in the volcanic terrain north of the valley, they act as upland recharge areas. The lavas also serve as important confined aquifers in the northwestern and northeastern portions of Honey Lake Valley, where they yield large amounts of ground water to irrigation wells.

Lahontan Lake and Near-Shore Deposits. Lake and near-shore deposits up to 700 feet thick accumulated during the Pleistocene epoch when Honey Lake Valley was occupied by Lake Lahontan. Coarse grained near-shore deposits form a discontinuous belt around the edge of the valley to an elevation of about 4,400 feet, and relatively fine grained lake deposits occupy the central part of the valley. The near-shore deposits are highly permeable and frequently occur above the water table where they act as important recharge

TABLE 17

GEOLOGIC FORMATIONS IN HONEY LAKE VALLEY

Geologic Age			Geologic Formation		Stratigraphy	Approximate Thickness in Feet
Cenozoic	Quaternary	Recent	Sand Deposits		Qs	0-25
			Lake Deposits		Ql	0-25
			Basin Deposits		Qb	0-50
			Intermediate Alluvium		Qal	0-100
			Landslides		Qls	0-50
			Alluvial Fans		Qf	0-300
		Pleistocene	Near-Shore Deposits		Qps	0-400
			Lahontan Lake Deposits		Qpl	0-700
			Pleistocene Volcanic Rocks	Basalt	Qpvb	50-500
				Pyroclastics	Qpvp	0-200
	Quaternary / Tertiary	Plio-Pleistocene	Plio-Pleistocene Volcanic Rocks	Basalt	TQvb	4000
				Pyroclastic Rocks	TQvp	?
	Tertiary	Pliocene	Pliocene Lake Deposits		Tpl	0-5000
			Pliocene Pyroclastic Rocks		Tpvp	1000
		Pre-Pliocene	Sierran Volcanic Rocks	Basalt	Tsvb	2000
				Andesite	Tsva	
				Pyroclastic Rocks	Tsvp	
			Auriferous Gravels		Tcg	?
			Gold Run Sandstone		Tgs	?
			Fort Sage Sandstone		Tfs	?
Mesozoic	Jurassic to Cretaceous	Basement Complex	Granitic Rocks		JKgr	?

Physical Characteristics	Water-Bearing Characteristics
Qsd: Loose, wind-blown sand.	Highly permeable but located above water table, hence contains little water.
Ql: Unconsolidated silt and clay, contains alkali.	Very low permeability and of little importance to ground water.
Qb: Unconsolidated sand, silt, and clay. Often contains alkali.	Low permeability. May yield small amounts of water to domestic wells.
Qal: Unconsolidated sand, silt, and gravel with lenses of clay.	Moderate permeability. Yields small to moderate quantities of water to wells.
Qls: Unconsolidated mixtures of rock, sand, and clay.	Moderate permeability. May yield moderate quantities of water to wells in Hidden Valley.
Qf: Unconsolidated gravel, sand, and silt, with some clay lenses.	Moderate to high permeability. Yields large quantities of water to wells. May contain confined water.
Qps: Unconsolidated, poorly cemented, bedded gravel, sand, and silt.	Highly permeable. Frequently occurs above water table. Where saturated yields large quantities of water to wells and sumps.
Qpl: Poorly consolidated, bedded sand, silt, and clay.	Permeability ranges from low to high. Contains important aquifers in Honey Lake Valley. Often yields large quantities of water to wells.
Qpvb: Jointed basalt flows containing zones of scoria.	Moderate to high permeability. May yield large quantities of water to wells. Acts as forebay for ground water recharge.
Qpvp: Bedded mudflows and tuffs.	Low permeability, unimportant to ground water.
TQvb: Jointed, fractured flows of vesicular basalt with some pyroclastic rocks.	Moderate permeability, may yield moderate amounts of water to wells. May contain confined water. Important as forebay for ground water recharge.
TQvp: Pale-colored bedded tuff.	Unimportant to ground water.
Tpl: Bedded, consolidated sandstone, tuffaceous siltstone and diatomite.	Generally of low permeability. Locally may yield moderate quantities of water to wells. Contains confined water.
Tpvp: Massive, cemented tuff and mudflows.	Essentially impermeable.
Tsvb, Tsva, Tsvp, Tsv: Flows of fractured basalt, andesite, and minor amounts of other types of lava. Massive mudflows and tuffs.	Permeability ranges from poor to moderate. Basalt is generally above zone of saturation, is underlain by impermeable rock, and is unimportant to ground water. A few areas may contain perched ground water. Andesite and pyroclastic rocks are essentially impermeable.
Tcg: Semi-consolidated gravel, sand, and clay.	Low to moderate permeability. Yields water to many springs. Not important to ground water in Honey Lake Valley.
Tgs: Semi-consolidated, poorly cemented sandstone and shale.	Low permeability. May yield small quantities of ground water to wells.
Tfs: Consolidated, cemented sandstone.	Essentially impermeable.
JKgr: Massive, poorly jointed diorite. Locally weathered and decomposed.	Impermeable where fresh. Decomposed rock may yield small quantities of water to wells and sumps.

areas. Where saturated, they often yield large amounts of water to wells and sumps. The lake deposits contain a large number of highly permeable sand beds in the area northwest of Honey Lake and also in and just north of Long Valley. These sand layers form the most important aquifers in the valley as they provide large amounts of water to irrigation wells. In contrast, the lake deposits found east of Honey Lake and north of Herlong consist mainly of silt and clay of low permeability and are poor producers of ground water.

Recent Valley Sediments. Principal Recent valley sediments in Honey Lake Valley include basin deposits, intermediate alluvium, and alluvial fans. The basin deposits are thin, of very low permeability, and generally are a poor source of ground water. Intermediate alluvium occurs along most of the perennial streams where they enter the valley. The permeability of the intermediate alluvium is moderate, but it is usually less than 100 feet thick and yields only small to moderate amounts of ground water to shallow wells. The alluvial fans are of moderate to high permeability and may be as much as 300 feet thick. The fans yield large amounts of confined and unconfined ground water to irrigation wells, particularly in Long Valley south of Doyle. Other Recent valley sediments include sand deposits, Recent lake deposits, and landslides. These deposits are all fairly thin and of little importance to ground water. The main exceptions are the landslides in Hidden Valley. These landslides are of moderate permeability and yield moderate quantities of water to wells.

Influence of Geologic Structure on Ground Water

The major structural features of the Honey Lake Valley area are the multitude of major and minor faults. Most of the displacement along these faults has taken place since the latter part of the Pliocene epoch. Most of the faults trend in a northwesterly direction, but north and northeast trending cross faults are not uncommon. The geologic structure of Honey Lake Valley

is shown in generalized geologic sections A-A[1], B-B[1], and C-C[1]-C[2], shown on Figures 26, 27, and 28, respectively. These sections show the probable structural conditions to a depth of about 2,500 feet below the floor of the valley. Subsurface features shown on these figures, as well as locations of many of the faults shown on Plate 30, are from interpretation of data from a geophysical survey made of the valley floor area of Honey Lake Valley by the Department of Water Resources.

The entire southwestern side of Honey Lake Valley is bordered by the Honey Lake fault zone. This zone consists of a series of parallel faults. Vertical displacement of at least 8,000 feet along this fault zone is responsible for the uplift of the Diamond Mountains and the formation of the steep escarpment that bounds this side of the valley. Other major faults in the valley are the Antelope Mountain, Litchfield, Amedee, and Fort Sage faults. Movement along these latter faults has been from 2,000 to 5,000 feet in a vertical direction. As a result of all this faulting, the basement complex rocks have been broken into four fault troughs within the large depression that now forms the valley. The largest and deepest trough is centered around Honey Lake. Basement rock at the bottom of this trough occurs at a depth of approximately 5,000 feet beneath the lakebed, or 1,000 feet below sea level as shown on Figure 28. The northwestern end of the valley is formed by a trough centered around Johnstonville. Valley fill consists of over 2,000 feet of sediments and interbedded lavas. Geologic section A-A[1], shown on Figure 26, crosses this trough. The Long Valley arm is situated in a trough containing nearly 4,400 feet of fill material. The eastern part of Honey Lake Valley, north of the Fort Sage fault, is formed by a trough filled with about 2,200 feet of sediments and lavas.

Faulting and subsidence of the valley has had a pronounced effect on the Pliocene lake deposits. The forces accompanying fault movement have

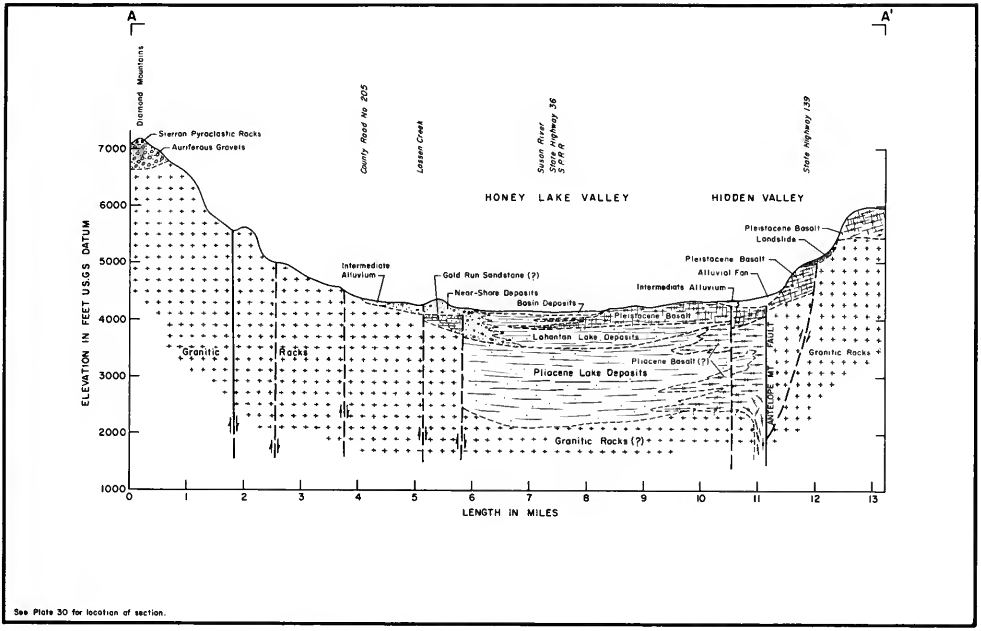


Figure 26. GENERALIZED GEOLOGIC SECTION A-A
HONEY LAKE VALLEY GROUND WATER BASIN

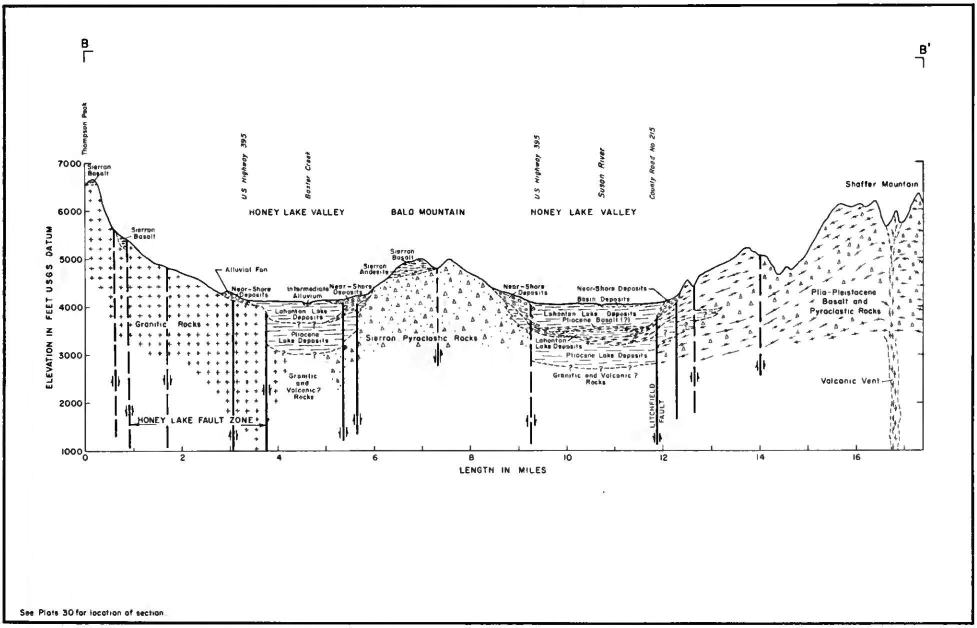
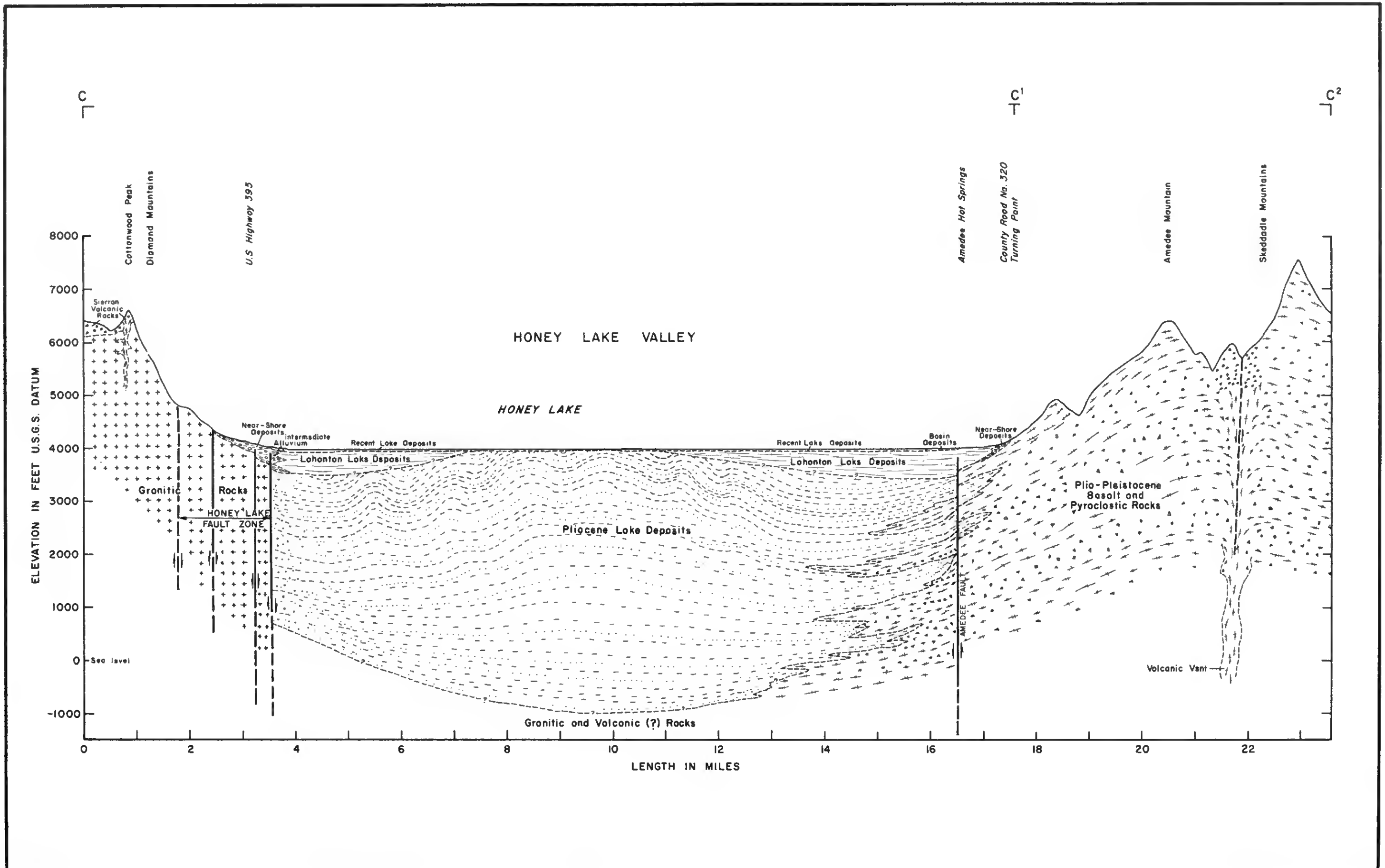


Figure 27. GENERALIZED GEOLOGIC SECTION B-B'
HONEY LAKE VALLEY GROUND WATER BASIN



See Plate 30 for location of section.

Figure 28. GENERALIZED GEOLOGIC SECTION C-C'-C²
HONEY LAKE VALLEY GROUND WATER BASIN

buckled these lake beds into numerous folds as shown diagrammatically on Figure 28. When the lake beds could no longer absorb these forces by folding, they failed along many small faults of low displacement. The overall effect of this folding and faulting has been to arch the Pliocene lake beds upward so that they are now exposed on the ground surface in the vicinity of The Island.

The faults and folds in Honey Lake Valley undoubtedly affect ground water movement. However, present data are insufficient to determine the detailed effects of these structural features. There appear to be no major fault barriers beneath the valley floor area. This may be because the Lahontan and younger sedimentary deposits probably have not been displaced by faulting.

Several faults in Honey Lake Valley act as conduits for the upward percolation of mineralized thermal waters. This water feeds Amedee and Wendel Hot Springs and several hot water wells in the southern part of Susanville.

The intense faulting along the Honey Lake fault zone has crushed the granitic rocks in many localities, thereby accelerating their weathering and decomposition. The weathered and decomposed zones are sufficiently permeable to transmit small quantities of water. These zones are tapped by many domestic and stock wells and also yield water to numerous small springs located along the base of the Diamond Mountains.

Recharge and Movement of Ground Water

The upland recharge areas, shown on Plate 31, consist of Plio-Pleistocene and Pleistocene basalt flows. Most of the recharge originates as precipitation which infiltrates the basalt and then percolates laterally to and beneath the valley floor area. An unknown amount of subsurface inflow may enter Honey Lake Valley from Secret Valley through Pliocene lake sediments which appear to be continuous beneath the lava field separating the two valleys.

Mean seasonal precipitation over Honey Lake Valley varies considerably, ranging from less than 4 inches in the eastern portion to about 14 inches near Susanville. Mean seasonal precipitation on the valley floor averages about 8 inches. The arid nature of most of Honey Lake Valley is due to a shadow effect caused by the mountains to the west which act as barriers to the prevailing movement of moisture laden storms. The mean seasonal precipitation on these mountains varies from 22 inches along the southwest to about 40 inches at the headwaters of Susan River. Precipitation on the peaks along the eastern boundary averages about 12 inches per year. Variation in the amount of seasonal precipitation can be expected to be similar to that at Susanville where a minimum of about 7 inches and a maximum of about 33 inches per year has been recorded.

Honey Lake Valley ground water basin contains both unconfined and confined ground water bodies, but data to define the separate bodies are lacking. Hence,the lines of equal elevation of water in wells shown on Plate 31 probably reflect a combination of the two conditions.

Because Honey Lake Valley is a closed basin with no surface outlet, ground water movement is largely controlled by topography, and the general direction of ground water movement is toward Honey Lake. Susan River, Gold Run Creek, and Baxter Creek appear to be effluent streams, i.e., are fed by ground water throughout a portion of their courses. Conversely, Long Valley Creek and Skedaddle Creek are apparently influent streams along a portion of their courses and contribute water to underlying aquifers during periods of intermittent flow. Both the effluent and influent streams affect the elevations of ground water and the movement of ground water in the areas adjoining their channels.

Flowing wells located along the northern edge of the valley floor south of the Amedee Mountains are probably supplied by ground water confined

in buried lava aquifers which are extensions of the lavas comprising the adjacent mountains. Flowing wells located along the southwestern edge of the valley floor tap confined aquifers in the lower portions of alluvial fans and adjoining near-shore deposits.

The essentially unconfined ground water in the vicinity of Herlong appears to be recharged by Long Valley Creek. Wells of the Sierra Ordnance Depot penetrate deep aquifers of confined ground water. The Island is apparently underlain by a shallow perched ground water body on top of the pre-Lahontan lake deposits.

Springs in Honey Lake Valley fall into three groups: springs which flow from joints and fissures in lavas in the northern and eastern parts of the valley; thermal springs which emerge along faults; and springs which result from the interception of the ground surface and the water table. Cady and Bagwell Springs, which are in the first group, furnish part of the water supply for the City of Susanville. Wendel and Amedee Hot Springs are prominent examples of the second type. The many small springs and seeps along the southwestern edge of the valley are of the third group.

Present Use of Ground Water

The major portion of the 21,000 acres of irrigated lands within the valley floor of Honey Lake Valley ground water basin receive irrigation water from Susan River. Irrigation water is obtained from both storage developments and direct diversion. The present supply of water from Susan River and other streams is insufficient to irrigate the 185,000 acres of valley floor lands classified as irrigable. During recent years, ground water has been developed to supplement surface water irrigation supplies. More than 2,600 acres are presently irrigated entirely from ground water. There are presently about 100 irrigation wells and about 500 domestic and stock wells in Honey Lake Valley.

The yields from some of these wells are insufficient for their intended use, while the yield from others exceeds 2,000 gallons per minute.

Ground Water Development Potential

Within the valley floor area of Honey Lake Valley ground water basin all four zones of potential for development of ground water are present. The area in each classification is shown on Plate 32. The general conditions which presently govern the potential for development of ground water within each zone in this basin are discussed below.

"A" Zone. The "A" Zone area located between Susanville and Johnstonvill is underlain by permeable lake deposits and buried lava aquifers which have excellent opportunity for recharge. The "A" Zone areas in the vicinity of Standish and Herlong are believed to be composed of coarse sands deposited respectively by ancestral streams along the courses of Susan River and Long Valley Creek. The "A" Zone area south of Doyle consists of coarse alluvial fan deposits adjacent to Long Valley Creek. Properly constructed and developed wells up to several hundred feet in depth in "A" Zone areas should produce high yields of ground water.

"B" Zone. "B" Zone areas are fairly well distributed throughout Honey Lake Valley, and most irrigation requirements can be supplied from the underlying permeable lake and near-shore deposits. If lava aquifers are found interbedded within the lake deposits, the ground water potential of these areas should approach that of the "A" Zone areas.

"C" Zone. The "C" Zone areas are relatively small with the exception of the "C" Zone area including Sierra Ordnance Depot. Only limited information is available concerning the subsurface materials in this latter area. The apparent lower permeability and the limited recharge opportunity, however, restrict its potential for ground water development. Wells located in

"C" Zone areas are expected to have only a fair development potential. Limited irrigation yields are possible but should not be expected.

"D" Zone. Areas classified as "D" Zone are composed of relatively thin deposits of permeable material and are found in areas adjacent to outcrops of impermeable rock. Wells located in "D" Zone areas are not expected to produce ground water in quantities sufficient for anything but domestic or stock use.

General. Honey Lake Valley ground water basin is unique among the ground water basins of the Northeastern Counties in that most of the good recharge areas are those with a minimum of precipitation. Areas with higher precipitation are not recharge areas in most of the region adjacent to Honey Lake Valley. The overall ground water development potential of the valley floor is good, but not as good as it would be if precipitation were greater over the better recharge areas.

There are large areas immediately north of Honey Lake where the water table is less than 5 feet below the ground surface. Lowering of the water table in summer months and allowing it to recharge in periods of high runoff could increase the yield of ground water from this area. Presently the high water table prevents the infiltration of additional water into the ground water body. Lowering of the water table below the root zone of native vegetation during the growing season would conserve for other uses the present consumptive use by native vegetation. This is estimated to be about 5 acre-feet per acre per year.

Ground Water Storage Capacity

Ground water storage capacity to a depth of 750 feet has been estimated to be about 16,000,000 acre-feet. How much of this quantity is usable, or how much usable storage exists below 750 feet is not presently known. It is

reasonable to assume that a significant amount of ground water could be developed.

Quality of Ground Water

Ground waters in Honey Lake Valley vary greatly in mineral quality. The ground waters in the valley south of Herlong and along the southwestern side of Honey Lake are usually excellent in quality and generally range from calcium to sodium bicarbonate in character. Similar waters are found south and west of Bald Mountain, near Buntingville and Janesville. These waters are suitable for most beneficial uses. Good quality ground waters are generally found in that portion of the Susan River drainage area northwest of Bald Mountain, but about 60 percent of the wells in the portion east of Bald Mountain yield poor quality waters. Some of these waters are not recommended for domestic use, while others are considered hazardous for irrigation use. A few are considered hazardous for either use. The ground waters found in the valley east of Honey Lake and north of the Southern Pacific Railroad are generally of good quality and are usually sodium bicarbonate in character. The few wells in the area east of Honey Lake between the Southern Pacific Railroad and Herlong yield poor quality waters of variable character.

Water Quality Problems

Ground waters in a closed basin such as Honey Lake Valley are continually subject to water quality impairment resulting from use and reuse. With each use some water is lost from the basin but most of the soluble salts remain, and with some uses additional salts are added. As a result, in the lower portions of a closed basin, poorer quality waters are usually found. As shown on Plate 32, two such areas within this basin contain ground waters of

hazardous quality. The poor quality waters found in these areas show great variation in both character and quality. Available water quality data indicate that although reuse is probably responsible for much of the impairment, some of it is the result of mineralized water rising along fault zones. Although waters of usable quality can be found within the two hazardous areas, more often waters containing excessive concentrations of boron, fluoride, nitrate, or an excessive amount of total dissolved solids will be encountered. Continuing reuse of ground waters may in the future cause increased impairment with the result that these waters may be rendered unusable.

Scattered throughout Honey Lake Valley are other wells yielding ground waters which contain excessive concentrations of one or more of the following constituents: boron, iron, fluoride, and nitrate. However, these appear to be only localized conditions of impairment.

Conclusion

Additional development of ground water in Honey Lake Valley appears promising. Adequate yields for stock and domestic purposes are available from relatively shallow wells throughout most of the valley. Generally, irrigation wells should be several hundred feet deep, and should be gravel packed to give satisfactory yields. Proper well construction and competent well development are essential if optimum yields are to be obtained.

Some of the valley floor is underlain by water of poor or doubtful quality. In a closed basin such as this, water quality will continue to be impaired by any development which contributes additional salts. Anticipated future development in Honey Lake Valley will be accompanied by population growth and expansion of urban and recreational areas. This growth and expansion will increase the demand for available water resources and will further aggravate the adverse salt balance in the basin.

Water quality considerations indicate the desirability of developing methods and techniques which will prevent: (1) the high sodium percentage waters from damaging the tilth and permeability of the soils; (2) serious problems from developing from industrial and domestic waste disposal; and (3) excessive accumulation of salts.

It is concluded that the basic data collection activities of the Department of Water Resources should be continued in order to facilitate future quantitative and qualitative analyses of the ground water basin. Encouragement should be offered to local agencies in their efforts to develop the ground water potential in the manner best suited to local problems and in accordance with information in this bulletin.

CHAPTER V. CONCLUSIONS

Little was known concerning the ground water basins of the northeastern counties of California prior to this investigation. Consequently, a major portion of the time and money allotted to the investigation was devoted to the collection of basic data. Generally, both the use of ground water within the area of investigation and the period for which data are available are insufficient to determine readily the factors needed to evaluate properly the sustained yield that could be developed. Preliminary evaluations of the potential for development of ground water were made to the extent warranted by the data collected.

Accomplishments

The primary accomplishments of this investigation are the following:

1. Significant new knowledge has been gained concerning geologic and ground water conditions in the northeastern counties. This new knowledge includes the following:

   a. Detailed description of physical and water-bearing characteristics of the area of investigation. During the study, 46 geologic units were described.

   b. Determination of ground water basin and subbasin boundaries.

   c. Preparation of a quantitative estimate of ground water storage capacity for all but two of the ground water basins.

   d. Determination of the geologic structure of the various ground water basins, and publication of geologic structure sections.

   e. Publication of geologic maps, at a scale of 1:125,000, of the ground water basins and surrounding territory totaling nearly 9,000 square miles.

f. Preparation of a detailed report on the ground water geology of each ground water basin.

2. The necessary foundation was completed for the collection of data required for continuing ground water studies. The following specific determinations were made.

a. Location and description of wells.

b. Detailed classification of wells.

c. Surveys to establish an elevation datum point for wells.

d. Measurement of water elevations in wells.

e. Analysis of water samples to determine suitability for beneficial use.

f. Location of wells to be used for obtaining data as to depth to ground water and quality of ground water under the department's continuing ground water measurement and ground water quality monitoring programs.

3. Preliminary evaluations were made of the potential for ground water development in the basins investigated. Four zones, A, B, C, and D, ranking from high to low, were established. Plates showing the estimated potential for ground water development indicate the classification for each area investigated.

4. Experience gained during this investigation will expedite the conduct of future ground water investigations in the northeastern counties.

Conclusions

In general, the extent and intensity of ground water development in the northeastern mountain valleys is low and does not constitute a

significant draft on the available ground water resources. This is indicated by the very small changes in water levels observed at most wells. Based on the data available, it is concluded that a significant potential for the development of ground water for irrigation use exists in portions of all ground water basins investigated. Water in quantities sufficient for stock or domestic purposes can be developed in almost all areas. To determine the potential in a particular basin, reference should be made to the discussion of the basin in question in Chapter IV.

Development of ground water resources can, and probably will, proceed through the efforts of individual water users to improve their supplies. This bulletin indicates the ground water potential to guide such development within the areas investigated. However, it should be noted that geologic conditions and the attendant potential for ground water in these areas are highly variable. When considering placement of an individual well, particular attention should be given to the geologic formations which the well would penetrate. The importance of proper construction of wells, as discussed in Chapter II, is emphasized both to insure proper functioning of the well and as a means to prevent the intermingling of poor quality waters with good.

As the use of ground water continues, the existing basic data collection activities of the Department of Water Resources in the concerned area should be continued. These activities serve to monitor and indicate the occurrence of problems associated with the availability and quality of the ground water resources. Similarly, the observation and experience of individuals and local agencies engaged in the development of ground water will serve to indicate special problems which may require additional geologic and engineering studies for their solution. In this regard,

the attention of all is called to the Ground Water Basin Protection Law, Chapter 7.5, Division 6, of the Water Code, which expresses the policy that the people of the State have a primary interest in the protection and preservation of our ground water basins.

APPENDIX A

DEFINITIONS

DEFINITIONS

<u>Andesite</u> — A volcanic rock, frequently porphyritic, varying in color from dark gray to reddish, and containing plagioclase feldspar and mafic minerals such as pyroxene, hornblende, and biotite. Andesite often occurs as lava flows or plugs.

<u>Anticline</u> — An upward fold in stratified materials.

<u>Aquiclude</u> — A geologic formation or zone which, although porous and capable of absorbing water slowly, will not transmit it rapidly enough to furnish an appreciable supply for wells or springs. A bed of clay is a typical aquiclude.

<u>Aquifer</u> — A geologic formation or zone sufficiently permeable to yield an appreciable supply of water to wells or springs. A bed of sand and gravel is a typical aquifer.

<u>Aquifuge</u> — A solid, impermeable mass of rock that contains no water. Nonweathered granitic rock is a typical aquifuge.

<u>Basalt</u> — The most common lava of flows. A dark gray to black rock composed principally of plagioclase feldspar and mafic minerals such as hornblende or pyroxene, with or without olivine.

<u>Confined Aquifer</u> — An aquifer overlain by an aquiclude.

<u>Conglomerate</u> — A consolidated sedimentary rock composed of rounded pebbles and cobbles contained in a matrix of finer material.

Diatomite — A deposit composed of microscopic shells of plants called diatoms.

Diorite — A moderately dark intrusive igneous rock of granitic texture, composed principally of plagioclase feldspar and hornblende, biotite, or other mafic minerals. Diorite is generally darker in color than granite.

Extrusive Igneous Rock — A rock poured out on the ground surface as from a volcanic vent -- a lava. Extrusive igneous rocks are fine grained to porphyritic and include andesite and basalt.

Formation — A fairly widespread group of rocks having characteristics or origin, age, and composition sufficiently distinctive to differentiate the group from other units. The formation is the fundamental geologic unit.

Gouge — A layer of soft, fine material occurring between the two walls of a fault, formed as a result of grinding movement.

Granite — A light colored intrusive igneous rock containing quartz, feldspar, and a small percentage of dark minerals such as biotite and hornblende.

Granodiorite — A common intrusive igneous rock of granitic texture, intermediate in color and mineral composition between granite and diorite.

Ground Water — Subsurface water occurring in the zone of saturation and moving under control of the water table slope or piezometric gradient.

Igneous Rock One of the three principal rock types. Igneous rocks are all formed as the result of solidification of molten rock. When the rock solidifies below ground surface, it is called "intrusive igneous." When it solidifies above the ground surface, as a lava, it is called "extrusive igneous." Common igneous rocks include basalt and granodiorite.

Intrusive Igneous Rock A rock that solidified beneath the surface of the earth. Instrusive igneous rocks are generally coarsely crystalline and include diorite, granite, and granodiorite.

Joint A fracture or parting in a rock mass along which no appreciable movement has occurred.

Lava Molten rock such as that which issues from a volcano or fissure, also such rock solidified. Most lava is of basaltic composition.

Magma Molten rock material within the earth, commonly generated at considerable depth.

Member A subunit of a formation.

Metamorphic Rock One of the three principal rock types. Metamorphic rocks are those which have been transformed under conditions of extreme heat and/or pressure from a sedimentary or igneous rock into an entirely different type of rock. Common metamorphic rocks include slate (metamorphosed shale), quartzite (metamorphosed sandstone), and meta-volcanic rocks (metamorphosed volcanics).

Mudflow — A flow of debris which is lubricated with a large amount of water; also such material solidified.

Obsidian — Volcanic glass. Although entirely different in appearance, obsidian has similar chemical composition to granite.

Permeability — The measure of the rate of movement of ground water through natural materials.

Piezometric Surface — An imaginary surface that everywhere coincides with the head of confined ground water in an aquifer. It is represented by the elevation to which water will rise in wells drilled into the aquifer.

Plug — The solidified cone of igneous rock in the throat of an old volcano. Sometimes applied to other dome-like masses of igneous rock.

Porphyritic — A texture of igneous rocks in which larger crystals occur in a finer groundmass.

Pyroclastic Rock — A rock formed of fragments ejected from a volcano, the fragments now generally cemented together. Pyroclastic rocks include volcanic ash, tuff, tuff breccia, and scoria.

Quartzite — A granular metamorphic rock composed essentially of quartz. It is generally a metamorphosed sandstone.

Rhyolite — A light-colored, fine-grained, igneous rock, often porphyritic; mineralogically similar to granite.

Rock Flour — Finely ground rock particles resulting from glacial abrasion.

Scoria	Volcanic slag; smaller scoria are volcanic cinders.
Sedimentary Rocks	One of the three principal rock types. Sedimentary rocks are the result of cementation, consolidation, and hardening of clays, silts, sands, and gravels. Common sedimentary rocks include shale, sandstone, and conglomerate.
Shale	A stratified rock, finely bedded or laminated, and formed by the consolidation of clay, mud, or silt.
Sill	A relatively thin body of igneous rock of nearly uniform thickness which has been emplaced between two formerly adjacent strata.
Slate	The moderately metamorphosed equivalent of shale.
Syncline	A downfold in stratified rock in which the beds dip toward a central axis.
Tuff	A rock formed from compacted volcanic ash.
Tuff Breccia	A rock formed of angular blocks of volcanic material contained in a matrix of tuff.
Vesicular	Containing many small openings (vesicles). Vesicular basalt is the result of the solidification of a lava charged with gas.
Volcanic Neck	The solidified lava filling the vent of a dead volcano.
Water Table	The surface of ground water at atmospheric pressure in an unconfined aquifer, as shown by the level at which water stands in a well penetrating the unconfined aquifer.

Welded Tuff — A tuff which has been hardened into lava-like rock by the action of heat at the time of ejection and deposition.

APPENDIX B

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